NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

WASHINGTON, D.C

CONTRACTOR FINAL REPORT

TEST #

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DOT HS-800 863

AN EVALUATION OF THE DYNAMIC PERFORMANCE CHARACTERISTICS OF ANTHROPOMORPHIC TEST DEVICES
Volume 3

Contract No. DOT-HS-053-1-129
May 1973
Final Report

PREPARED FOR
U.S. DEPARTMENT OF TRANSPORTATION
NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION
WASHINGTON, D C 20590

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT HS-800 863		

4. Title and Subtitle	5. Report Date
An Evaluation of the Dynamic Performance Characteristics of Anthropomorphic Test Devices (95th Percentile Anthropomorphic Test Dummy) Volume 3	May 1973
	6. Performing Organization Code
7. Author(s): James B. Walunas and J. Sam Miller	8. Performing Organization Report No.: FA-5018-V-3 Volume III
9. Performing Organization Name and Address: Calspan Corporation, 4455 Genesee Street, Buffalo, N.Y. 14221	10. Work Unit No.: N69 Series
	11. Contract or Grant No.: DOT-HS-053-1-129
12. Sponsoring Agency Name and Address: U. S. Department of Transportation, National Highway Traffic Safety Administration, Washington, D. C. 20590	13. Type of Report and Period Covered: FINAL (Volume III) June '71 - Nov. '72
	14. Sponsoring Agency Code

15. Supplementary Notes

Additional results from component and accelerator sled tests of 50th percentile dummies are contained in supplemental reports FA-5018-V-1 and FA-5018-V-2, respectively.

16. Abstract

An experimental investigation was conducted to assess the dynamic performance of a state-of-the-art 95th percentile anthropomorphic dummy under conditions approximating those expected in vehicle compliance testing.

This report covers the work performed under Amendment Nine of Contract DOT-HS-053-1-129.

17. Key Words	18. Distribution Statement
Restraint Systems Anthropometric Test Devices Dummies - Test	unlimited available through the National Technical Information Service, Springfield, Virginia 22151

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
unclassified	unclassified	99	

Form DOT F 1700.7 (8-69)

FOREWORD

This volume is the third of a three-volume final report documenting the results of an experimental investigation of the static and dynamic performance characteristics of state-of-the-art anthropomorphic test dummies. In this volume, results obtained from measurements of a Sierra Engineering Company Model 292-1295 95th percentile male dummy supplied by the Government are presented.

The reported research was performed by the Calspan Corporation for the National Highway Traffic Safety Administration of the U.S. Department of Transportation under Contract DOT-HS-053-1-129. The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the National Highway Traffic Safety Administration.

This report has been reviewed and approved by:

for Raymond R. McHenry
Edwin A. Kidd, Head
Transportation Research Department

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1.0 INTRODUCTION

This report documents the results obtained in the performance of tasks described in Amendment No. 9 of Contract DOT-HS-053-1-129 pertaining to static and dynamic measurement of a 95th percentile anthropomorphic test dummy. The purpose of these experimental measurements was to obtain data that could be used to establish the general conformance of the anthropometry of this dummy to accepted values for a 95th percentile adult male, and to allow comparison of its dynamic performance in a restraint system test configuration with that of a 50th percentile male dummy. Previously, the only such anthropometry data available was that supplied by the dummy manufacturers.

The specific measurement objectives were as follows:

1. Determine the dimensions, weights, centers of gravity and pivot locations of the body segments, and the joint ranges-of-motion.

2. Determine the head impact response characteristics.

3. Determine the static and dynamic deflection properties of the head-neck assembly and of the chest assembly.

4. Obtain the basic response of the dummy in simulated 30 mph impacts under four-point restraint conditions.

In general, these measurements of the 95th percentile dummy were performed using essentially the same techniques and equipment that were employed for measuring the performance of standard and modified 50th percentile dummies in the earlier phases of the research program. Detailed descriptions of the test procedures, instrumentation, facilities, and data analysis procedures are contained in Volume I of this final report.

2. SUMMARY

The 95th percentile dummy evaluated on this project was a Sierra Model 292-1295. This dummy is a seated position design, similar in basic construction to the Sierra Model 292-1050 50th percentile dummy. In addition to the changes needed for obtaining a larger size and weight, a new chest rib cage assembly and a new wooden head were also incorporated in this dummy, and minor modifications were made in joint design.

All of the required measurements were obtained without experiencing difficulty, and the measured values were as one would expect for a slightly larger dummy. No serious malfunctions of the dummy were encountered, however, some cracks appeared in the wooden head, and a tear developed in the soft cover around the lumbar spine during the sled impact tests.

Specifically, the test measurements revealed:

1. Anthropometry: All body segment weights and lengths were increased over those measured for the 50th percentile version, not necessarily in proportion but with an average increase in component size of about 10% (over the values given in SAE J963). The seated height only increased by 6%, and the most notable differences were in the torso, with a 19% increase in chest circumference, a 30% increase at the waist and a 49% increase at the buttocks. The overall weight increase was 31%, with the largest change being the 44% increase in torso weight. The weight distribution among the three torso segments was also substantially different from the distribution among the corresponding segments of the 50th percentile dummy previously measured. However, all the body segment centers of gravity and body pivot locations were within expected values for the larger dummy. The joint ranges-of-motion did not completely agree with the 50th percentile values of SAE J963, in that the head flexion range was 13 degrees less than the minimum specified, and the hyperextension

and lateral flexion of the torso exceeded the maximu[illegible] by 25 and 15 degrees respectively.

2. Head Impact Drop Tests: A severe high [illegible]uency ringing response was obtained for this wooden head in respon[illegible] [illegible]ll levels of impact, and therefore this model head is less satisfactory than any of the previously tested aluminum or fiberglass type heads.

3. Static Neck Deflection: The measured spring rate of the neck of this completely assembled dummy was approximately 50% greater in stiffness than previously measured Sierra rubber necks. This increase is probably due to the compression of the skin coverings at the junction of the [illegible]ck and torso

4. Dynamic Neck Deflection: Arrested pendulum measurements of the isolated head-neck dynamic response resulted in approximately the same amplitude, natural frequency and damping as obtained during previous tests of the Sierra rubber neck with a 50th percentile Alderson head.

5. Static Chest Deflection: The chest of this dummy was much softer under static loading than the chests of previously measured dummies.

6. Dynamic Response to Pendulum Impacts at the Chest: The overall magnitudes of the resulting forces and deflection were comparable to those measured on the 50th percentile Alderson dummies, but the shape of the initial portion of the force-deflection response curve is indicative of a system with much less inertia at initial impact.

7. Simulated 30-MPH Barrier Impacts in the 4-Point Belt Restraint Sled Tests: In general, the measured response parameters of this dummy were comparable to those measured for the 50th percentile dummies in the same restraint configuration. The mean Head Injury Criteris (HIC) value was higher by 21%, but the run-to-run repeatability was essentially the same

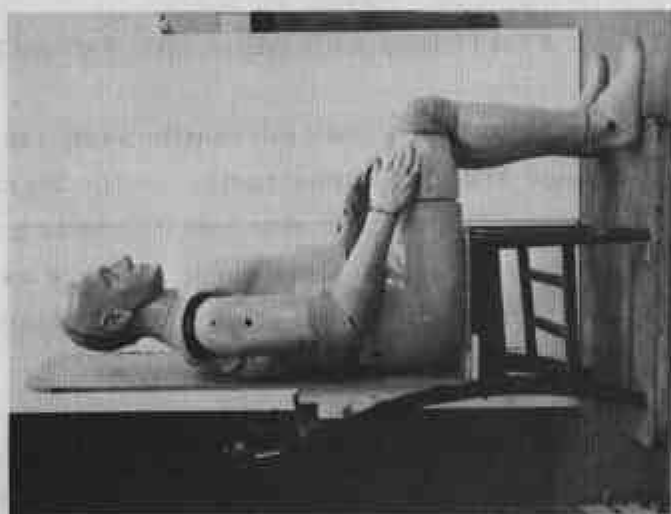
as obtained for the 50th percentile dummies. The maximum chest accelerations were the same, with very repeatable time histories. The lap belt load was unexpectedly about 10% less, but the shoulder belt loads were higher in accordance with the increased weight, with a 19% and 6% increase for the upper and lower anchors respectively. A severe submarining effect was present in all three of the sled tests, as compared with the 50th percentile Sierra dummy sled tests where a slight submarining response was seen in one of the six sled runs.

3. DUMMY PHYSICAL FEATURES AND GENERAL APPEARANCE

The Sierra Model 292-1295 is a 95th percentile seated dummy design and is similar in appearance and basic construction to the Sierra Model 292-1050 50th percentile dummy. The overall size and weight is greater, and it has a wooden head and a new design for the chest rib cage assembly. Some minor modifications were made in the joint design intended to provide easier access and maintainability of joint torque settings.

The fully assembled dummy is shown in Figure 1. The skin covering has joint access holes that permit adjustment of most joints without removal of any parts. The usual zipper fasteners have been replaced with Velcro type fasteners, which are less vulnerable to damage than zippers, and which held together well during the tests.

The internal construction details are shown in Figure 2. The core of the head form is a laminated wood ballasted with lead weights. A cable tension adjustment for the neck torque requires removal of the head. The resting angle of the head, with respect to the torso, is adjustable between 5 degrees of neck hyperextension and 30 degrees of flexion. The two discs near the base of the neck are friction adjustments for the shoulder elevation motions. Each rib in the chest assembly is individually articulated, attached to the rigid spine section and to the leather sternum with pivot points. They are flat, slant downward, and the intercostal space contains a connective resilient material, such that the construction is anatomically very realistic. The lumbar spine section has discs similar to the Sierra 292-1050, except that they are encased in a soft pliable cylinder. Adjustment of the torque setting for the lumbar spine requires removal of the lower torso skin and padding. The extremity joint design is essentially the same as in the Sierra 292-1050 model.



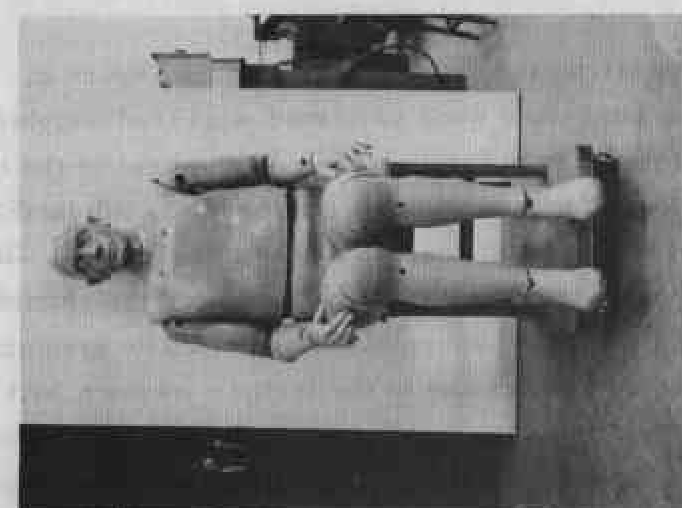


Figure 1 ASSEMBLED SIERRA MODEL 292-1295 DUMMY

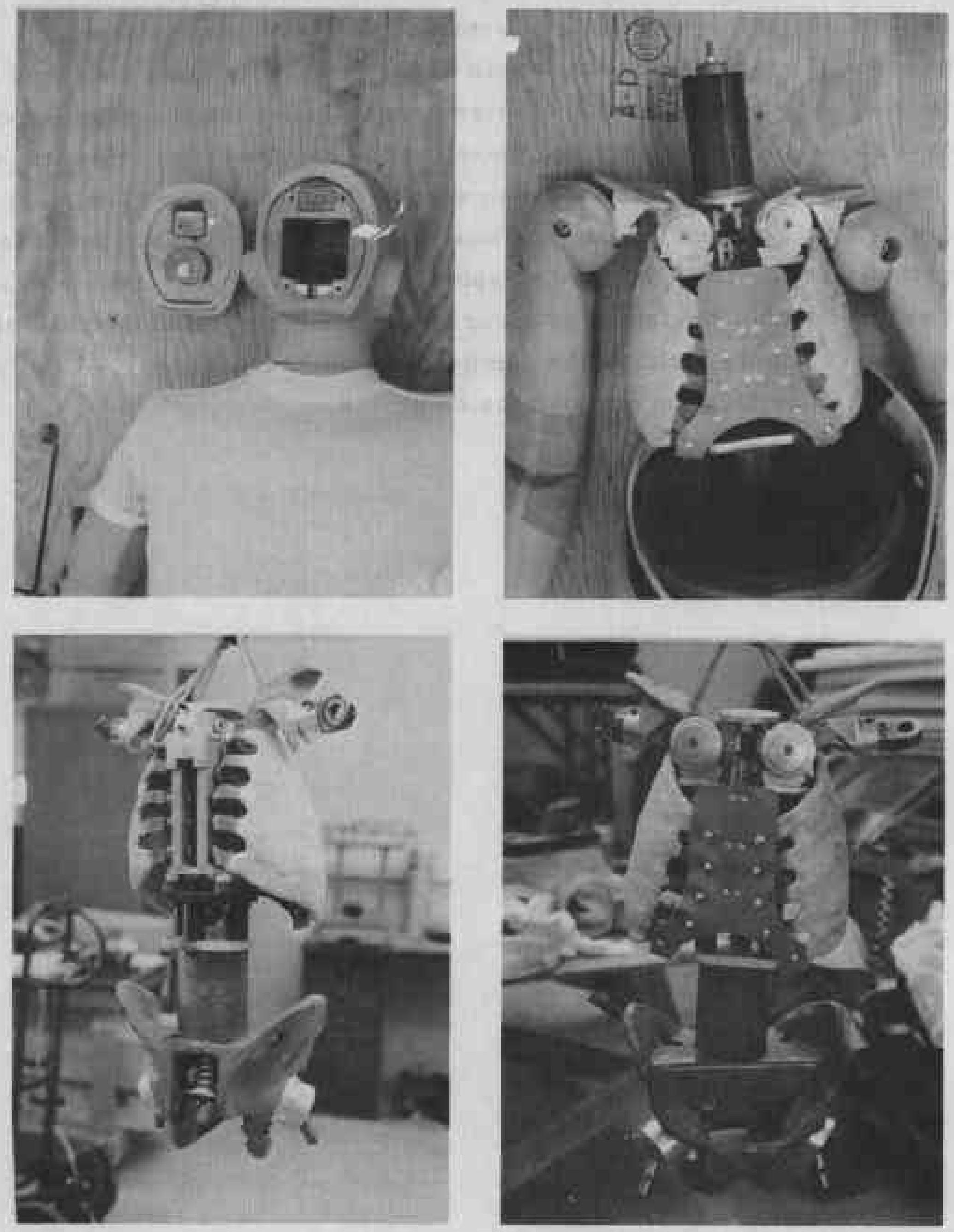


Figure 2 HEAD AND TORSO SKELETAL STRUCTURE OF SIERRA MODEL 292-1295 DUMMY

No functional problems occurred as a result of the testing program, however some minor damage to components was evidenced, such as abrasion of the skin and tearing of internal foam and plastic parts. Several small cracks were noted both in the removable skull plate and in the back of the wooden head, the latter originating at the threaded screw holes in the head. It is believed these cracks resulted from impacts of the head with the back of the Calspan seat in the sled tests. The most severe internal component damage was to the plastic cylinder that encases the articulated joints of the lumbar spine. The wall of the cylinder was split several inches beginning at a corner of a bolt clearance notch in the top surface. Figure 3 shows the lumbar spine discs and damaged cylinder with the fracture location outlined for emphasis.

Figure 3 DAMAGED LUMBAR SPINE CYLINDER

4. STATIC AND DYNAMIC PERFORMANCE MEASUREMENTS

This section describes the measurement procedures and results obtained in seven groups of measurements, as defined in the contract Amendment No. 9, tasks one through five. Wherever possible, each measurement was performed in the same manner as previously developed for measuring the characteristics of the 50th percentile dummies, such that some basis for comparison would exist. The specific routines and instrumentation details are fully described in Volume I of this report, but are summarized in this section for completeness.

4.1 Anthropometric Measurements of the Components and Assembled Dummy (Task 1)

The requirements* for Anthropometric measurements were:

a. Measurements of the 95th percentile male dummy and determination of its body segment weights, centers of gravity, and dimensions in accordance with the designation of Table 1 and Figure 1 of SAE J963 Recommended Practice, June 1968.

b. Measurement of the ranges of motions of the 95th percentile male dummy including items A, B, C, AC, AE, AD and AF as designated in the Table 2 and Figure 3 of the SAE J963 Recommended Practice, June 1968.

c. Measurement and establishment of the body pivot locations for the 95th percentile dummy in accordance with designations of Figure 4 of this report.

*As stated in the Contract.

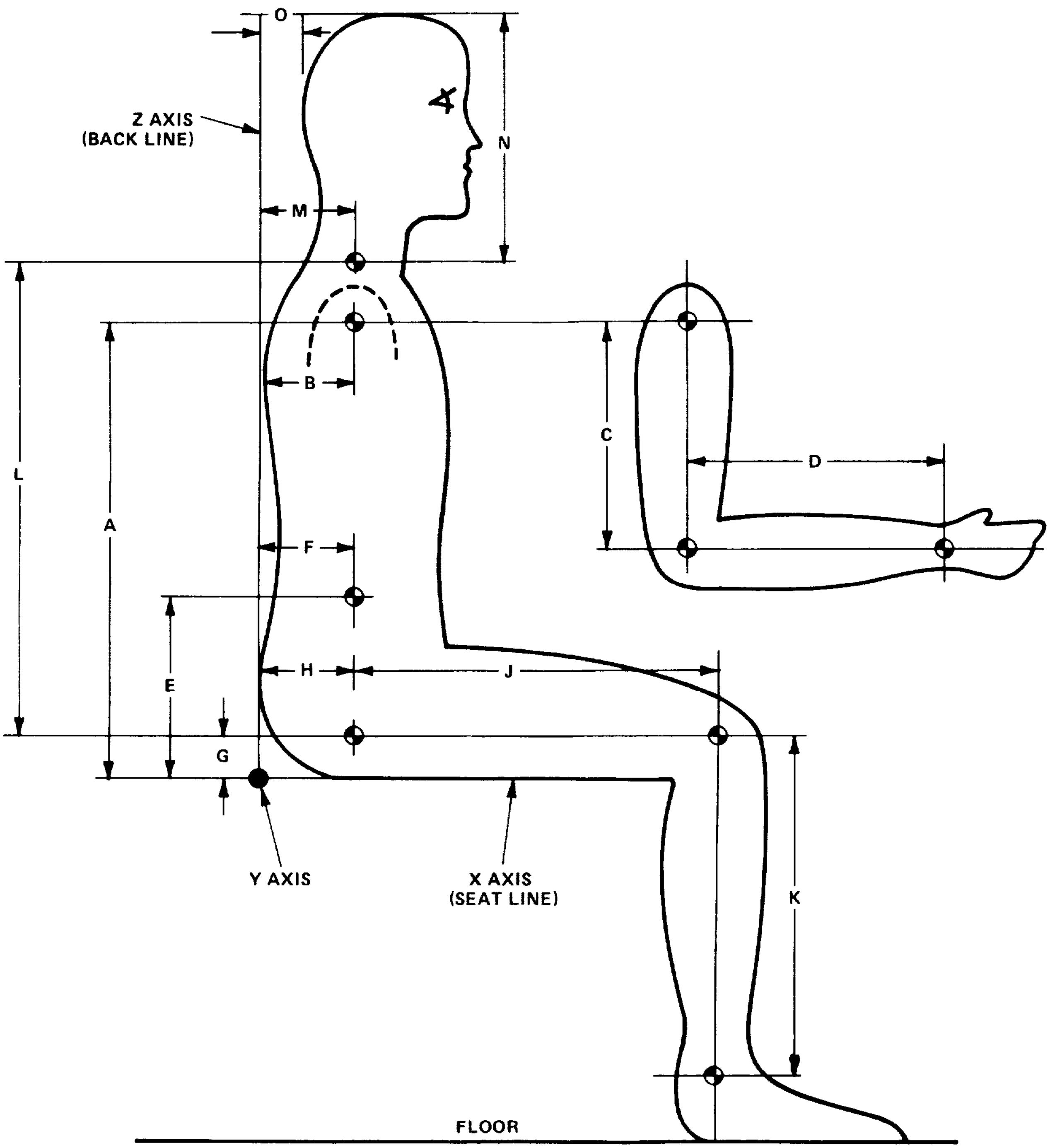


Figure 4 PIVOT LOCATIONS IN THE X-Z PLANE

FA-5018-V-3

In order to clarify the meaning and intent of a "95th percentile" dummy, a brief review of the major considerations involved in such a definition is presented here. The term, "95th percentile" refers to the point on a distribution curve for a specified variable where 95% of the measured (or calculated) values would be less, and hence 5% would be greater than that particular value. In the specific case of the adult male population in the United States, the median or 50th percentile standing height is 68.3 inches and the 95th percentile standing height is 72.8 inches (these and the following statistics are according to Stoudt et al, Reference 1, and Roberts, Reference 2). Similarly, a 50th percentile weight of 166 pounds and a 95th percentile weight of 217 pounds is given.

The problem arises in defining the height <u>and</u> weight of a "95th percentile" adult U.S. male. The average weight of a man who is 72.8 inches tall is not 217 pounds, it is 188 pounds and, similarly, the average height of a man who weighs 217 pounds is not 72.8 inches, it is 69.1 inches. There is some general positive correlation between height and weight, but by no means can they be considered to be related on a one-to-one percentile basis.

However, for the purpose of testing restraint systems, it is desirable to define a dummy that has both 95th percentile height and weight values. This does not mean, however, that 5% of the U.S. adult male population will exceed both the 72.8 inches and 217 pounds of the 95th percentile dummy. (Actually, 13.3% of the men who weigh 217 pounds are taller than 72.8 inches, due to a very skewed curve.) So for the purposes of standardizing dummy definitions, we recommend that a "95th percentile" dummy should weigh 217 pounds, and at the same time have a height corresponding to the 95th percentile height of the U.S. adult male. SAE J963 specifies a seated height dimension, presumable because the dummies are designed to function primarily in the sitting position, and for a 95th percentile dummy, this dimension should be 37.9 inches.

A secondary problem exists in defining the length and weight of the segments of the dummies. Again, if the 95th percentile values for length of each segment were used to make up a dummy, the overall height of that dummy would be much greater than the 95th percentile value for overall height. The reason for this is simply that in nature, the body segment lengths are not always in proportion to the overall length. For example, a fair number of persons with long legs have short midsections, and vice-versa, such that the 95th percentile of combined lengths is shorter than the sum of the two individual segment 95th percentile values taken independently. A similar situation exists for weight distribution. A linear scaling-up from the 50th percentile segment values could be used to solve the problem, but the actual measured distribution (Reference 1) does not behave in this linear manner. In addition, no such measured distributions for segment weights have been published.

One approach to this problem of determining proper representative segment weights and dimensions for a "95th percentile" dummy is a digital computer program being developed by Calspan for the Motor Vehicle Manufacturers Association. This computer program is designed to compute segment link dimensions, surface dimensions, weights, and moments of inertia from a primary set of input parameters (standing and seated heights and total weight, expressed either in inches and pound units or as percentiles) for use in conjunction with mathematical models of the crash victim developed by Calspan. The program (Reference 3) uses a set of human dimensional data that are based on actual measured distributions, and operates on these values to determine segment sizes for given input conditions. The segment weights are then computed on a volumetric basis using the calculated segment dimensions and known segment densities. In this manner, the segment weights are more realistically related to true body proportions than the values that would be obtained by scaling up or down from the 50th percentile values. The values for segment size and weight, as computed by this program for the 95th percentile weight, seated height, and standing height, are shown in Tables 1 and 2 for comparison to the measured 95th percentile dummy values.

TABLE 1

DUMMY SEGMENT DIMENSIONS (Inches)

Letter Designation [1]		Measured 95th Percentile Dummy	Calspan Computed 95th Percentile	SAF J963 50th Percentile Dummy
AB[2]	Head	11.4[5]	9.7	9.3
AC[3]	Shoulders	20.9	[6]	16.9
AD[4]	Abdomen	29.7	[6]	25.1
K	Buttocks	14.9[5]	10.1	10.0
I	Shoulder - Elbow Length	15.7	15.4	14.1
J	Elbow Rest Height (erect)	10.2	9.8	9.5
L	Popliteal Height	18.0	16.2	17.3
M	Knee Height (sitting)	22.9	23.0	21.4
N	Buttock Popliteal Length	19.6	20.1	19.5
O	Chest Depth	11.1	9.8	9.0
P	Buttock Knee Length	24.1	25.5	23.3
Q	Thigh Clearance	6.8[5]	5.8	5.7
R	Elbow-Finger Tip Length	20.0	20.1	18.7
S	Foot Length	12.0	11.0	10.5
T	Head Length	8.4	8.1	7.7
U	Sitting Height (erect)	38.0	37.9	35.7
V	Shoulder Breadth	20.1	19.1	17.9
W	Foot Breadth	3.9	4.3	3.8
X	Head Circumference	24.4	22.9	22.5
Y	Chest Circumference	45.0	37.6	37.7
Z	Waist Circumference	45.0	34.5	33.0
AA	Head Breadth	6.3	6.4	6.1

(1) Refer to Table 1 and Figure 1 of SAE Recommended Practice J963, June 1968
(2) Top of head to break in neck skin
(3) Top of head to lower end of spine member for rib attachment
(4) Top of head to interface of lumbar spine with pelvis
(5) Not directly comparable due to differences in segment divisions
(6) Not directly computable

TABLE 2

DUMMY SEGMENT WEIGHTS (Pounds)

	Measured 95th Percentile Dummy		Calspan Computed 95th Percentile		SAE 1963 50th Percentile Dummy	
Head/Neck[1]	17.5[2]		18.5		11.2	
Shoulders and Upper Thorax (Upper Torso)	41.9	112.0	26.0	100.5	17.3	77.8
Lower Thorax and Upper Abdomen (Center Torso)	15.0		40.6		23.0	
Lower Abdomen, Buttocks, and Upper Thighs (Lower Torso)	55.1		33.9		37.5	
Upper Arm - Left	7.0		6.8		5.4	
Upper Arm - Right	6.6		6.8		5.4	
Forearm - Left	3.9	5.6		5.3	3.4	4.8
Hand - Left	1.7				1.4	
Forearm - Right	3.8	5.5		5.3	3.4	4.8
Hand - Right	1.7				1.4	
Upper Leg - Left	17.4[2]		24.0		17.6	
Upper Leg - Right	17.8[2]		24.0		17.6	
Lower Leg - Left	8.9		9.6		6.9	
Lower Leg - Right	9.2		9.6		6.9	
Foot - Left	3.5		3.3		2.8	
Foot - Right	3.7		3.3		2.8	
Total Test Device Weight	214.7		217.0		164.0	

(1) Including accelerometer mounting block.

(2) Not directly comparable due to differences in segment divisions.

Regarding the joint range-of-motion requirements, it is recommended that they be the same as those for the 50th percentile dummy rather than the 95th percentile values on the range-of-motion distribution curves. The reason for this recommendation is that in all likelihood the correlation between range-of-motion and total body weight is probably negative. Persons who are heavier would be expected to have less than normal range of motion due to muscle and body fat interference. For this reason a 95th percentile dummy with above average ranges-of-motion would not be at all realistic or representative.

The measurement of the dummy segment weights in accordance with the SAE J963 divisions required that the torso be considered in three parts designated as the upper, center, and lower torso. Figure 5 shows how the dummy was partitioned to approximate the three torso segments. The results for weight, length and center of gravity are presented in Tables 1, 2, and 3, respectively. The measured angular ranges of motion of the Sierra 292-1295 dummy are shown in Table 4 which also lists the motion ranges recommended in SAE J963 for 50th percentile dummies. The pivot points were located as indicated in Figure 4 and those results are given in Table 5. The lumbar pivot is not a fixed point and is defined as the pivot location when the dummy is bent over with the chest touching the upper legs.

The tools and equipment used to make these measurements are of standard tool and diemaker quality and include such items as a beam trammel, protractor or inclinometer, balanced beam scales calibrated to ±0.2 pounds, and an assortment of rulers and squares. The accuracy of the dimensional measurements is estimated to be about ±1/8 inch with the exception of the center of gravity location which is believed to be accurate within ±1/4 inch. The joint motion range measurements are probably accurate to within ±2 degrees.

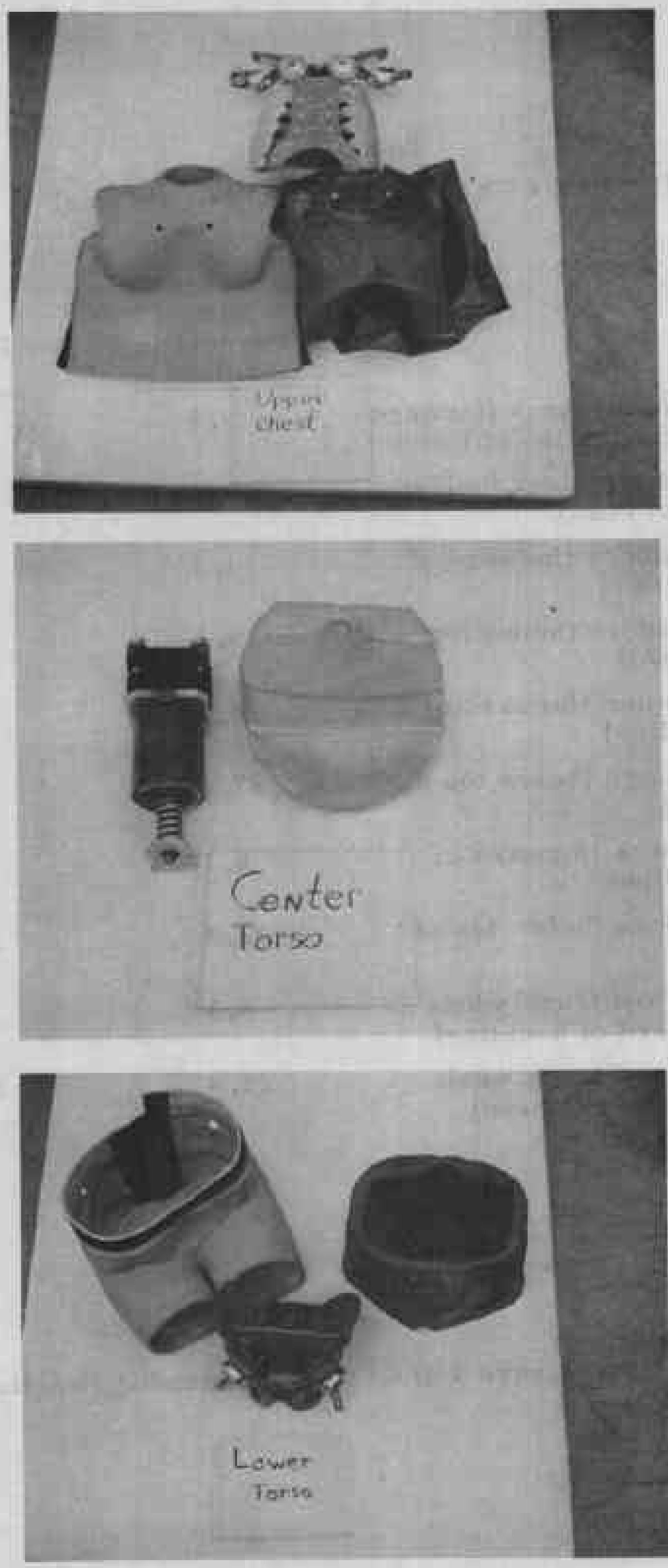


Figure 5 COMPONENTS OF SIERRA MODEL 292-1295 DUMMY TORSO SEGMENTS

TABLE 3

DUMMY CENTERS OF GRAVITY (Inches)

Letter(1) Designation			Measured 95th Percentile Values	SAE J963 50th Percentile Values
A		Head and Neck (forward from backline of body)	5.5	4.0
B		Head and Neck (below top of head)	6.1	4.7
C	Upper Torso	Shoulders (forward of backline)	4.4	3.8
D	Upper Torso	Shoulders (below top of head)	19.1	14.1
E	Center Torso	Abdomen (forward of backline)	4.7	4.9
F	Center Torso	Abdomen (below top of head)	27.2	20.8
G	Lower Torso	Buttocks (forward of backline)	5.1	5.3
H	Lower Torso	Buttocks (below top of head)	32.3	31.2
		Head and trunk whole (forward of backline)	5.1	4.7
		Head and trunk whole (below top of head)	23.4	22.7

(1) Refer to Table 1 and Figure 1 of SAE Recommended Practice J963, June 1968.

TABLE 4

ANGULAR RANGES OF MOTION (Degrees)

Letter Designation[1]		Measured 95 Percentile Values	SAE J963 Values
A	Head-Torso Hyperextension	47 [2]	60 + 45
B	Head-Torso Flexion	47	60 + 10
C	Head-Torso Lateral Flexion	$\pm$47 [2]	$\pm$40 $\pm$ 10
AC	Torso Flexion	60 *	40 (Min)
AE	Torso Hyperextension	60 [2]	30 + 5
AD	Torso Lateral Flexion	60 [2]	35 + 10
AF	Torso Rotation	42	35 + 10

*Chin Contacts Chest

(1) Letter designations correspond to those used in Table 2 and in Figure 3 of J963 SAE Recommended Practice.

(2) There is no hard stop and deflection can continue until one body part engages another or the structure fails.

TABLE 5

BODY PIVOT LOCATIONS

Dimension Symbol[1]	Description	Value (inches)
A	Shoulder Pivot to Seat Line	22
B	Shoulder Pivot to Back Line	5.1
C	Shoulder Pivot to Elbow Pivot	11.6
D	Elbow Pivot to Wrist Pivot	10.2
E[2]	Lumbar Pivot to Seat Line	9.1
F	Lumbar Pivot to Back Line	4.1
G	Hip Pivot to Seat Line	4.9
H	Hip Pivot to Back Line	5.9
J	Hip Pivot to Knee Pivot	15.1
K	Knee Pivot to Ankle Pivot	17.9
L	Lower Neck Attachment Centerpoint to Hip Pivot	21.8
M	Lower Neck Attachment Centerpoint to Z Axis	4.8
N	Top of Skull to Lower Neck Attachment Centerpoint	12.3
O[3]	Occiput to Z Axis	-.5 to +3.5

(1) Symbols correspond to those given in Figure 4.

(2) For chest touching upper legs position.

(3) This distance is adjustable within the range specified.

The body segment weight and length values for the 95th percentile dummy are, in general, larger than the 50th percentile dummy values but not in exact proportion. The average increase in length was about 10% but, for example, the increase in sitting height was only 6%. Most noticeable were the torso dimensional increases of 19% for chest circumference, 0% for the waist circumference and 49% for the buttocks width. These values are much larger than the 95th percentile Calspan calculated values, which agree within 10% of those measured by others (see Sahley, Reference 4). The total weight increase was 31%, with most of the weight added to the torso which increased by 44%. The individual torso segments varied considerable but this can be attributed to different arbitrary dividing lines. The centers of gravity are as expected, except for the buttocks, where the mass appears to be concentrated towards the rear rather than extending forward in accordance with the increased size.

The actual angular range-of-motion values did not meet the SAE J963 recommended values for three of the seven joints measured. The head-torso flexion angle was 13 degrees less than the recommended minimum range due to chin contact with the chest. The torso hyperextension and lateral flexion ranges are considerably greater than the maximum recommended (by 25° and 15° respectively). The locations of the body pivot points appeared to be reasonable.

4.2 Free Fall Drop Tests of the Head Assembly (Task 2)

The requirements* for the measurement of head impact response to free fall drop tests were:

1. Free fall drop tests of the 95th percentile dummy's head shall be made on a rigidly supported steel block at least two inches thick and two feet square. Three tests each shall be made from heights of 10, 20, and 35 inches, as measured from the steel block to the impact point on the forehead.

*As stated in the contract.

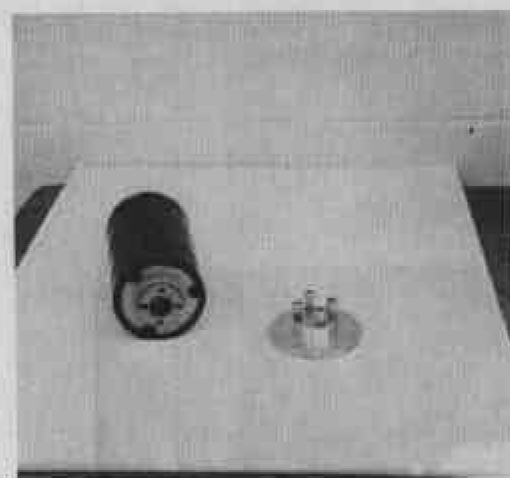
2. The desired impact point is located on the forehead in mid-sagittal plane two inches below the top of the head.

3. The head shall be suspended in configurations as shown in Figure 6 so that at the instant of impact the enclosed angle between the head upper-lower line and horizontal plane is nominally 30 degrees.

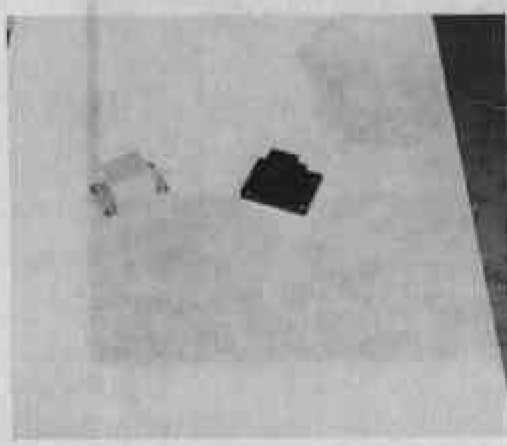
The above requirements were met with the exception of the impact angle and impact point on the forehead. That is, the shape of the head was such that these two conditions were imcompatible and the head orientation angle was, therefore, increased to 34° $\pm 1°$ to avoid first contact with the nose of the dummy. The resulting point of impact on the forehead was about 1-1/2 inches below the top of the head.

The wooden head was instrumented with a Kistler Model No. 833 (Serial No. 937) triaxial accelerometer having a range of 750G. Although the head came equipped with an accelerometer mounting block, it was too small for attachment of the accelerometer. Therefore, a modified accelerometer block was fabricated. Since the accelerometer mounting block is attached to a metal plate which, in turn, is held firmly in the head only when the head is attached to the neck, it was also necessary to machine an adapter plate similar to the end plate of the rubber neck for the drop tests. Photos of these fabricated components and the original parts for which they were substituted are shown in Figure 7.

Figure 6 SETUP FOR DROP TEST OF SIERRA MODEL 292-1295 DUMMY WOODEN HEAD



NECK ADAPTER PLATE



ACCELEROMETER MOUNTING BLOCK

Figure 7 FABRICATED COMPONENTS FOR DROP TESTS OF SIERRA MODEL 292-1295 WOODEN HEAD

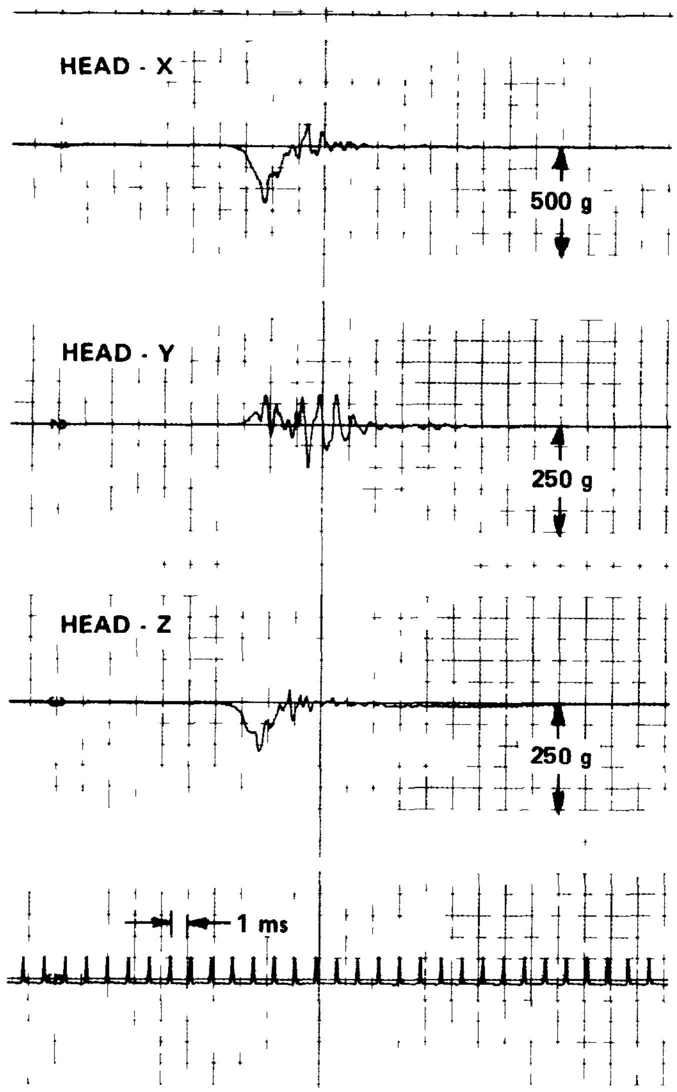
Table 6 is a listing of the actual test schedule, and Figures 8, 9, and 10 are the recorded head acceleration responses for the 10-inch, 20-inch, and 35-inch drop heights, respectively. Compared to the responses measured in similar tests of the Alderson fiberglass and standard aluminum heads (reported in Volume I), the wooden head produced an unexpectedly large ringing response, and appears to have peak accelerations and impulse durations comparable to the Alderson aluminum heads. The amplitude of the ringing oscillation is about one-third the amplitude of the impact impulse, and is the same amplitude in the lateral (Y) direction. Several supplementary drop tests of the head were made using other accelerometers and with the accelerometer mounting block removed to determine if the observed ringing responses were perhaps due to faulty instruments or the method of mounting. Because the results of these tests were not much different, it is concluded that the measured responses are in fact a manifestation of a lightly damped vibrational mode of the head structure having a frequency in the range between 1150 and 1600 cps and cannot be filtered without impairing the ability to adequately measure actual hard impact situations. This head is not recommended for use in compliance testing because this ringing response will yield higher HSI or HIC numbers than a non-ringing response, and these higher numbers are not meaningful for general comparison or interpretation.

TABLE 6

SCHEDULE - FREE FALL HEAD DROP TESTS

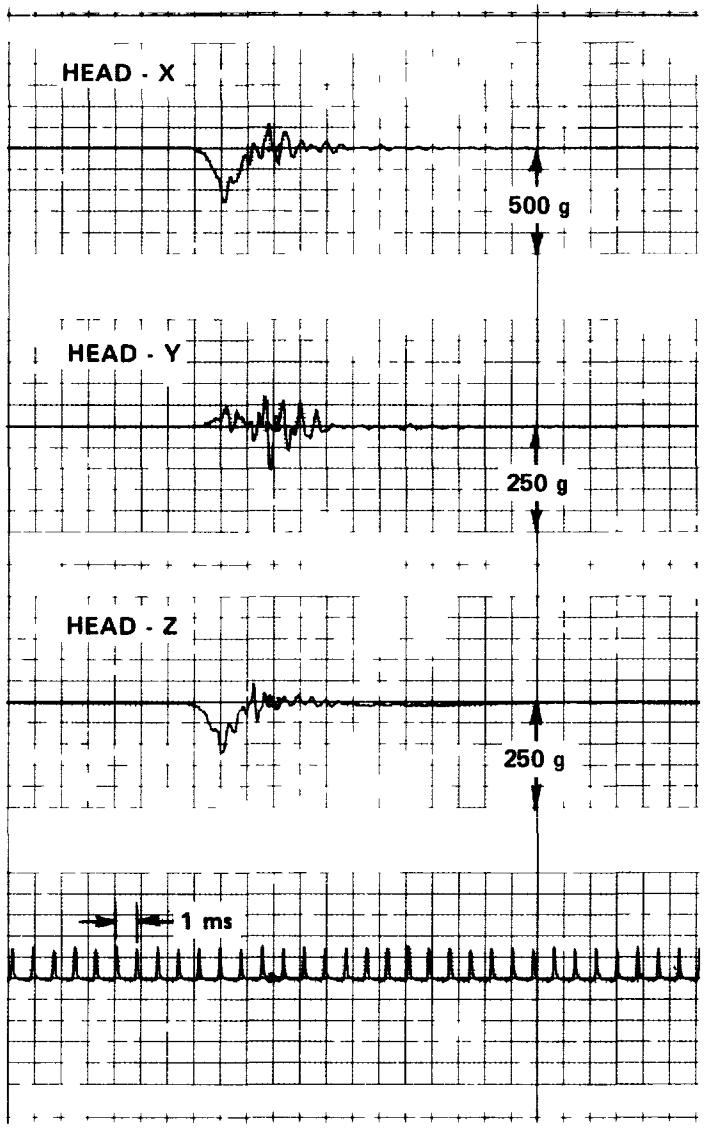
SIERRA MODEL 292-1295 DUMMY

Run No.	Drop Height/(Inches)	Impact Velocity (fps)
D-1	10	7.3
D-2	10	7.3
D-3	10	7.3
D-4	20	10.3
D-5	20	10.3
D-6	20	10.3
D-7 (Not reported)	30	12.7
D-8	35	13.7
D-9	35	13.7
D-10	35	13.7



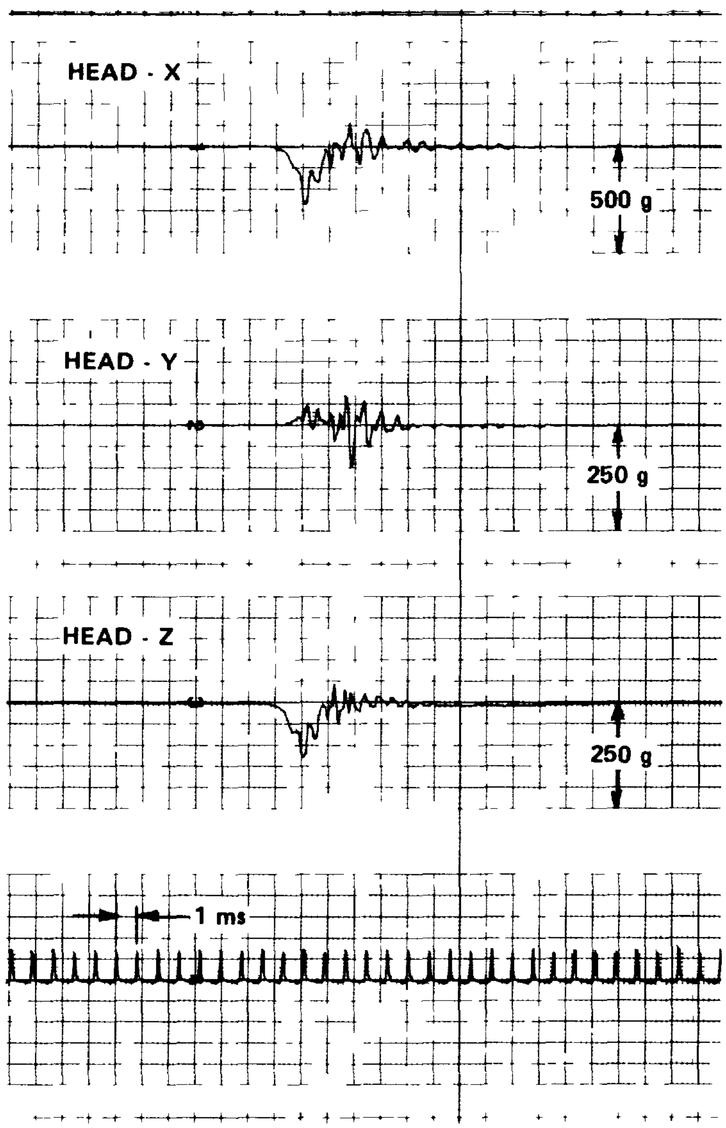
a. RUN (D-1), FIRST OF THREE REPEATS

Figure 8 HEAD ACCELERATION RESPONSE TO 10-INCH DROP IMPACT TEST — SIERRA 292-1295 DUMMY WOODEN HEAD



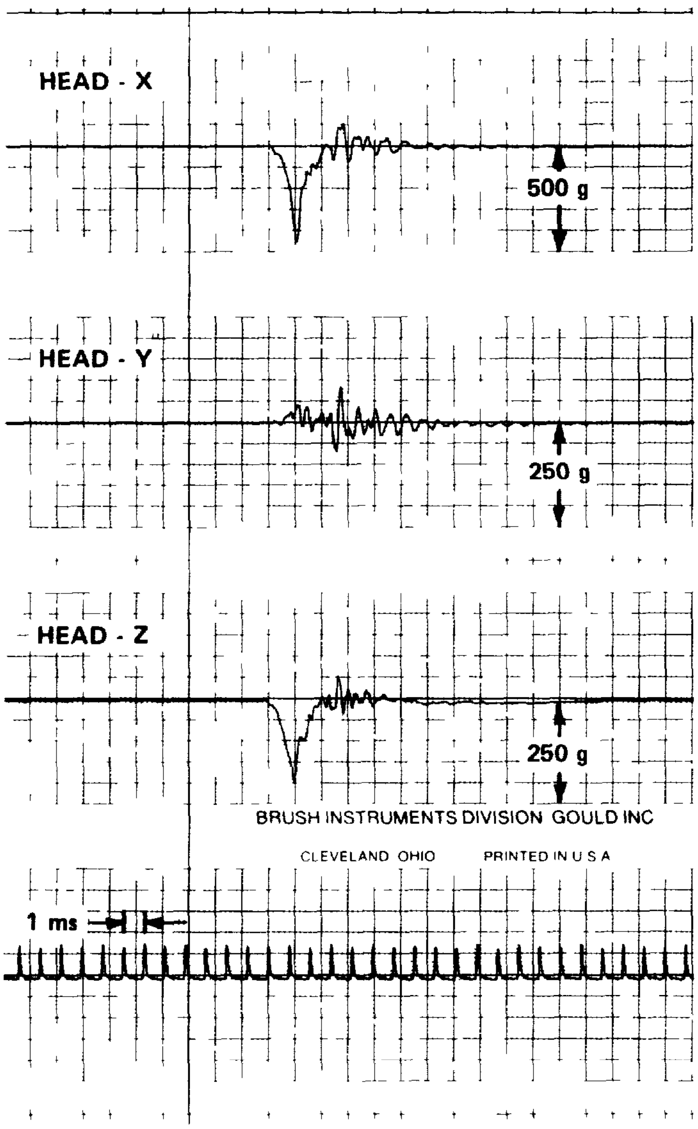
b RUN (D-2), SECOND OF THREE REPEATS

Figure 8 (Cont'd.)



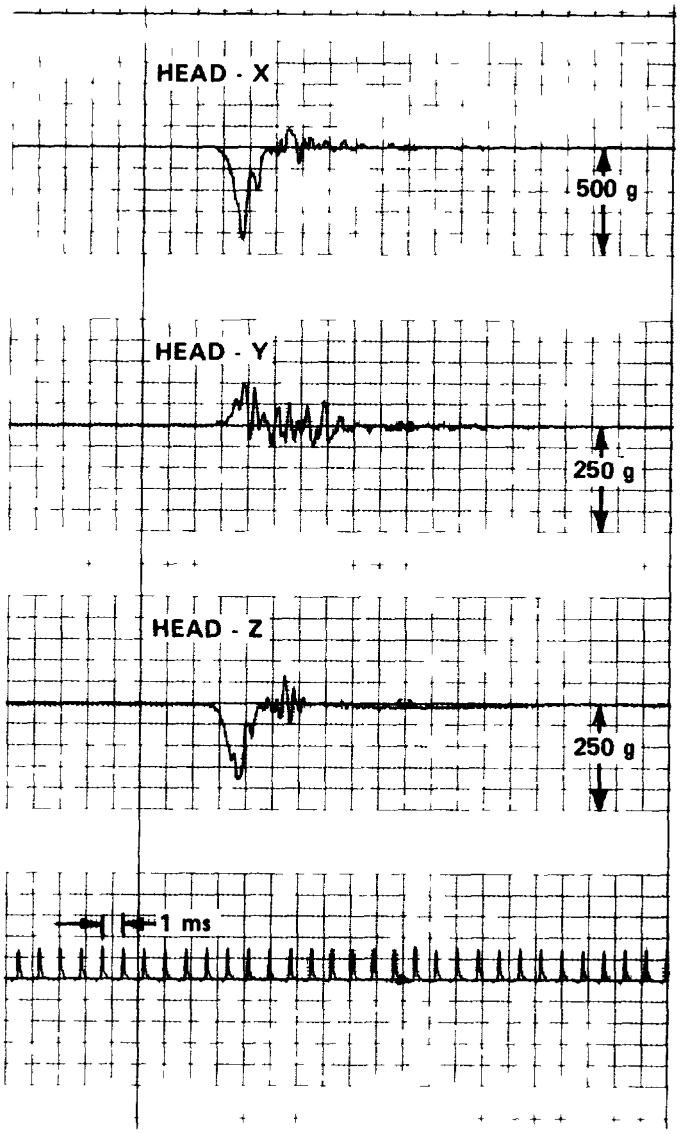
c. RUN (D-3), THIRD OF THREE REPEATS

Figure 8 (Cont'd.)



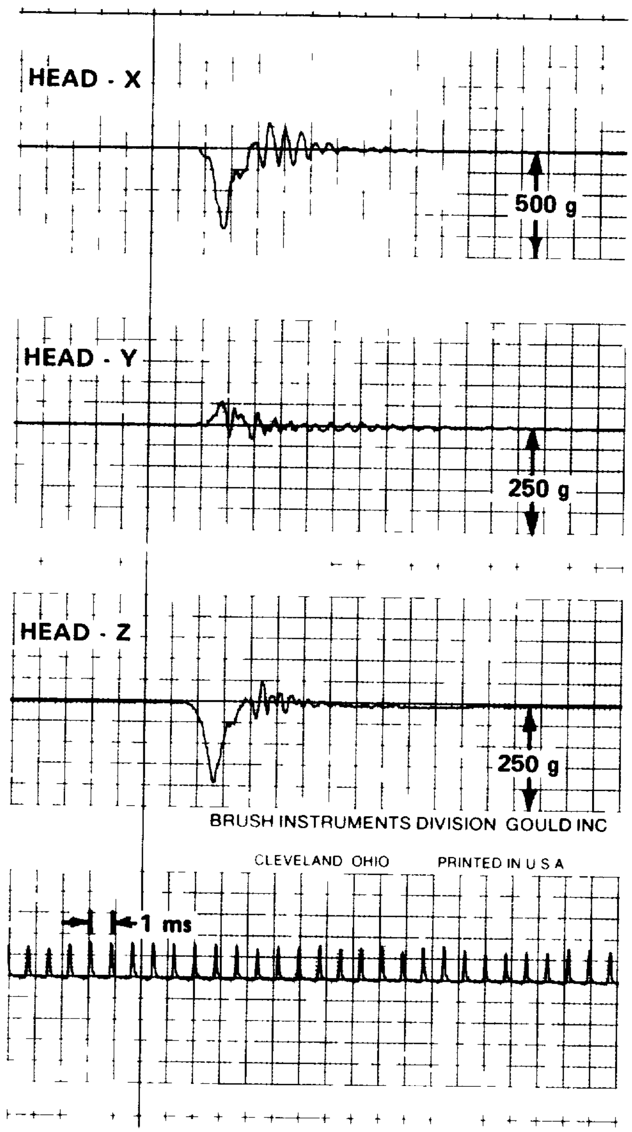
a. RUN (D-4), FIRST OF THREE REPEATS

Figure 9 HEAD ACCELERATION RESPONSE TO 20-INCH DROP IMPACT TEST SIERRA 292-1295 DUMMY WOODEN HEAD



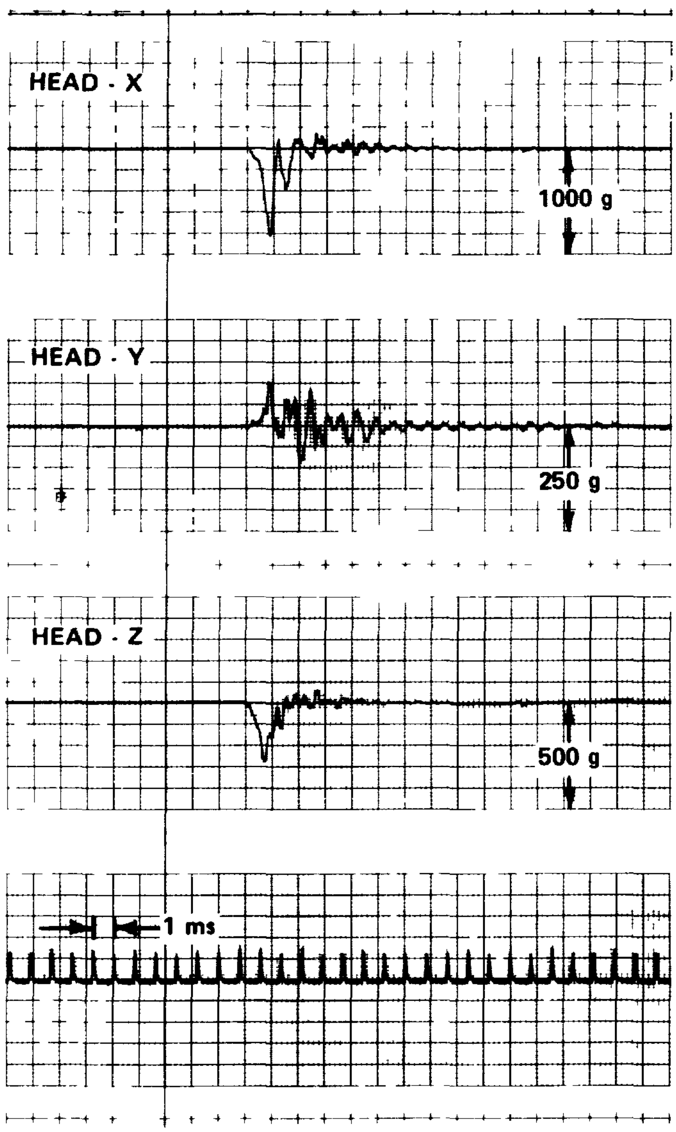
b. RUN (D-5), SECOND OF THREE REPEATS

Figure 9 (Cont'd.)



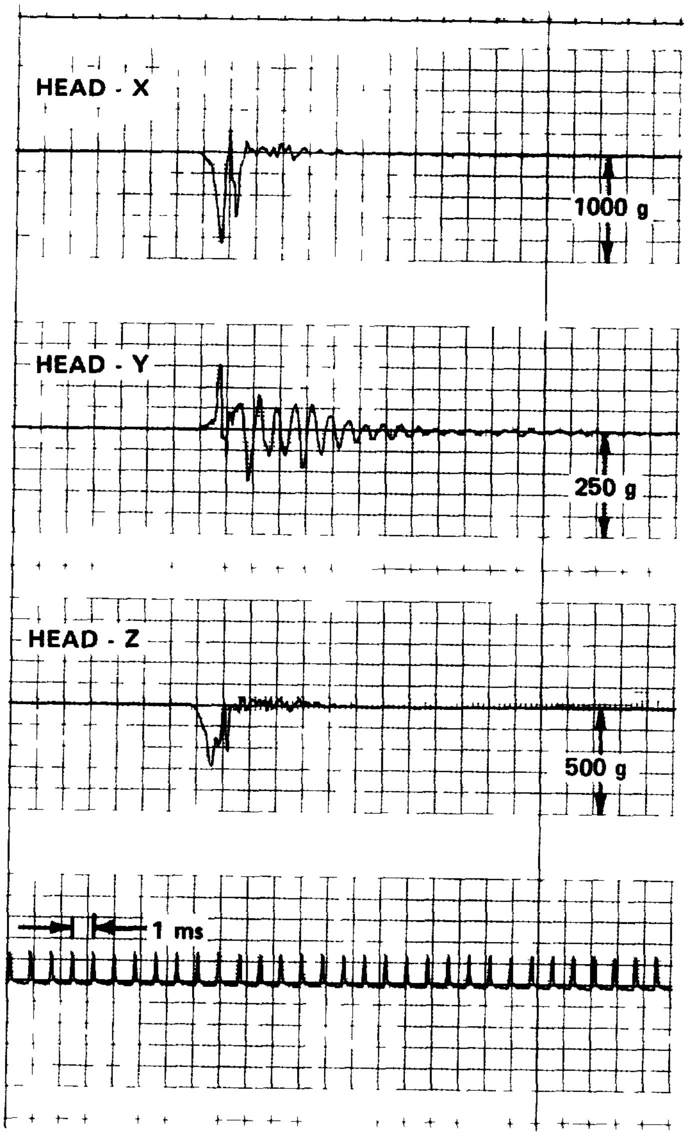
c RUN (D-6), THIRD OF THREE REPEATS

Figure 9 (Cont'd.)



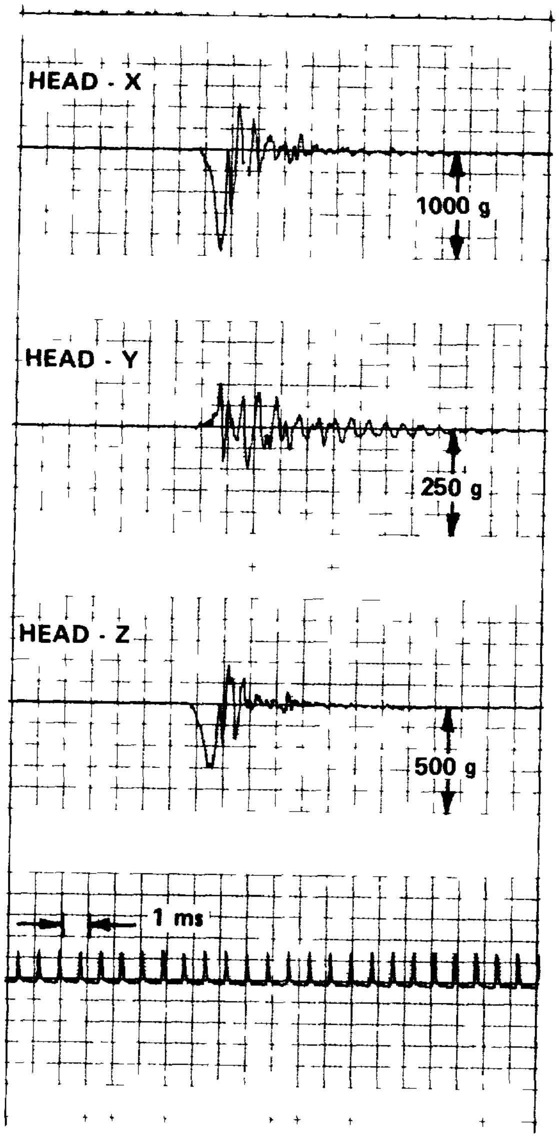
a. RUN D-8), FIRST OF THREE REPEATS

Figure 10 HEAD ACCELERATION RESPONSE TO 35-INCH DROP IMPACT TEST SIERRA 292-1295 DUMMY WOODEN HEAD



b. RUN (D-9), SECOND OF THREE REPEATS

Figure 10 (Cont'd.)



c. RUN (D-10), THIRD OF THREE REPEATS

Figure 10 (Cont'd.)

4.3 Static Load Deflection of the Head/Neck Assembly (Task 3a)

The required procedure for the measurement of the static load deflection characteristics of the head/neck assembly was as follows:

1. The back of the torso is firmly attached to a flat surface to preclude its motion in any direction.
2. The upper-lower centerline of the head-neck is set forward ten degrees from the torso upper-lower centerline. This is initial or zero position for the measurement purposes.
3. The head eyebolt is adjusted for the center of the eye to be six inches above the CG of the dummy's head.
4. A force is applied in mid-sagittal plane to the eyebolt in a direction perpendicular to the upper-lower centerline of torso, and during the head flexion, the direction of the force is adjusted to keep it perpendicular to this line. The loading rate does not exceed ten degrees of flexion per second.
5. The force-angular flexion readings are taken at ten degree intervals until a change in force-deflection slope is reached.
6. During the head-neck flexion, measurement of the head CG linear displacement will also be made.

The results of this measurement are shown in Figures 11 and 12. The initial upper-lower centerline of the head/neck zero load orientation of 10° forward flexion was obtained by adjusting the pivot provided at the base of the rubber neck. The applied loads were controlled within ±2 pounds, and the angle read to the nearest 1/2 degree with an

'As stated in the contract.

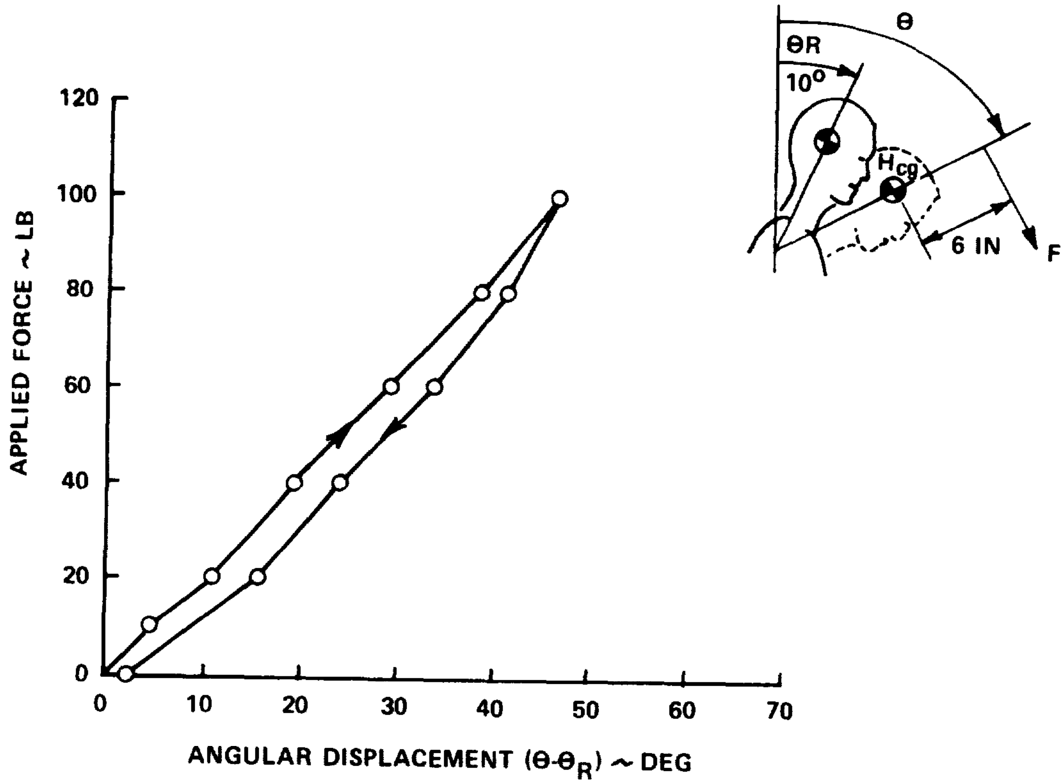


Figure 11 STATIC FORCE-DEFLECTION OF SIERRA MODEL 292-1295 DUMMY HEAD/NECK

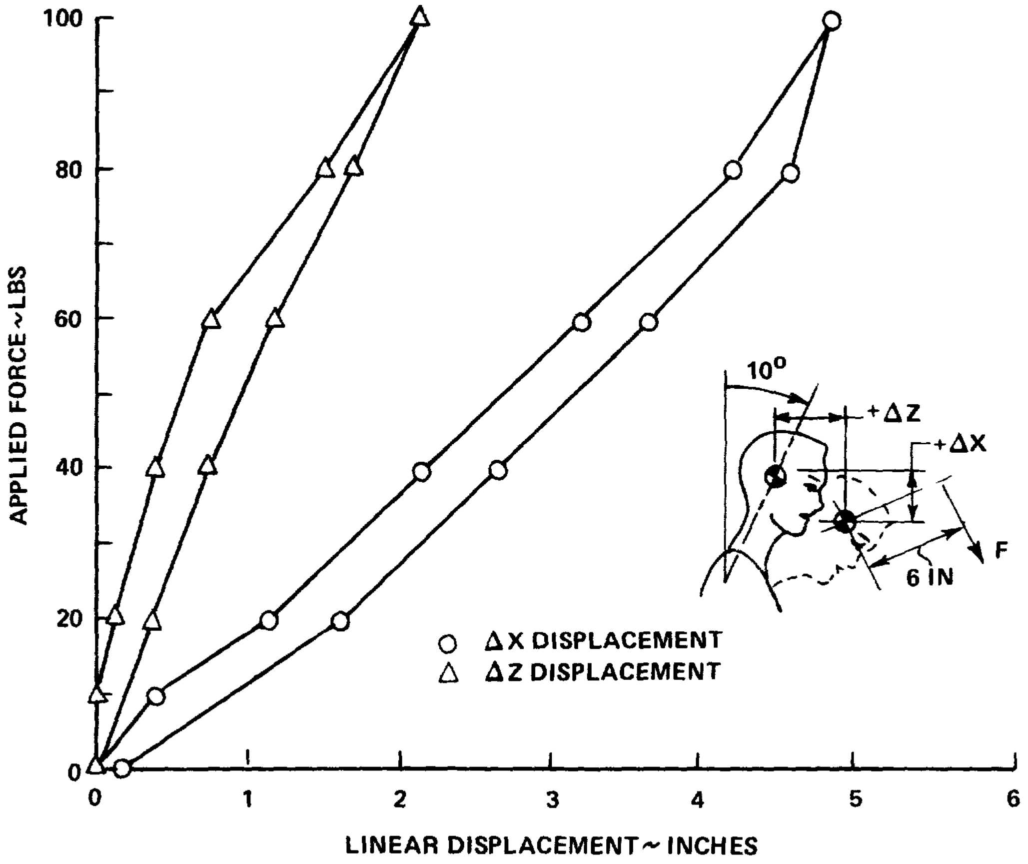


Figure 12 STATIC FORCE DISPLACEMENT CHARACTERISTICS OF A SIERRA MODEL 292 - 1295 DUMMY HEAD/NECK

inclinometer. The stiffness of this head/neck combination is much greater than that of the 50th percentile dummy with the same type of neck as tested previously (see Volume I). The increased stiffness (2.2 lb./degree versus 1.5 lb./degree) may be due to greater interference of the neck skin with the skin of the upper torso in this particular dummy.

4.4 Arrested Pendulum Tests of the Head/Neck Assembly (Task 3b)

The required test procedure for measuring the dynamic loading head-neck deflection characteristics for the 95th percentile dummy specified three arrested pendulum impacts as follows:

1. The head-neck is mounted on the pendulum used for testing of the 50th percentile dummies, the head-neck mid-sagittal plane coinciding with the pendulum vertical centerline and pendulum motion plane, and the head-neck superior-inferior axis remaining parallel (but offset.5-1 inches if needed for the chin not to contact pendulum) to pendulum centerline.
2. The free falling pendulum is decelerated from the tangential velocity of 26 ft. /sec., measured 65.2 inches from the point of pendulum suspension, with a square wave pulse having an amplitude of 24-26 G's for a time duration of 36-40 ms.
3. The pendulum and head acceleration time histories are recorded in accordance with the provisions of the SAE J211 Recommended Practice, dated October 1970, and angular and linear deflection time histories determined for the head CG.

The pendulum apparatus dimensions and head/neck location are shown in Figure 13. An aluminum honeycomb block was used as an energy-absorbing stop that would produce a nearly square-wave deceleration pulse. The honeycomb specifications are given in Table 7 and Figure 14 shows a used test sample. The mass, center of gravity locations and mass moment of inertia for the pendulum were experimentally determined with and without the head/neck test package, and are given in Table 8. The desired impact velocity of 26 fps measured at 65.2 inches from the pivot axis centerline was verified by a photocell velocity measuring device. The

*As stated in the contract.

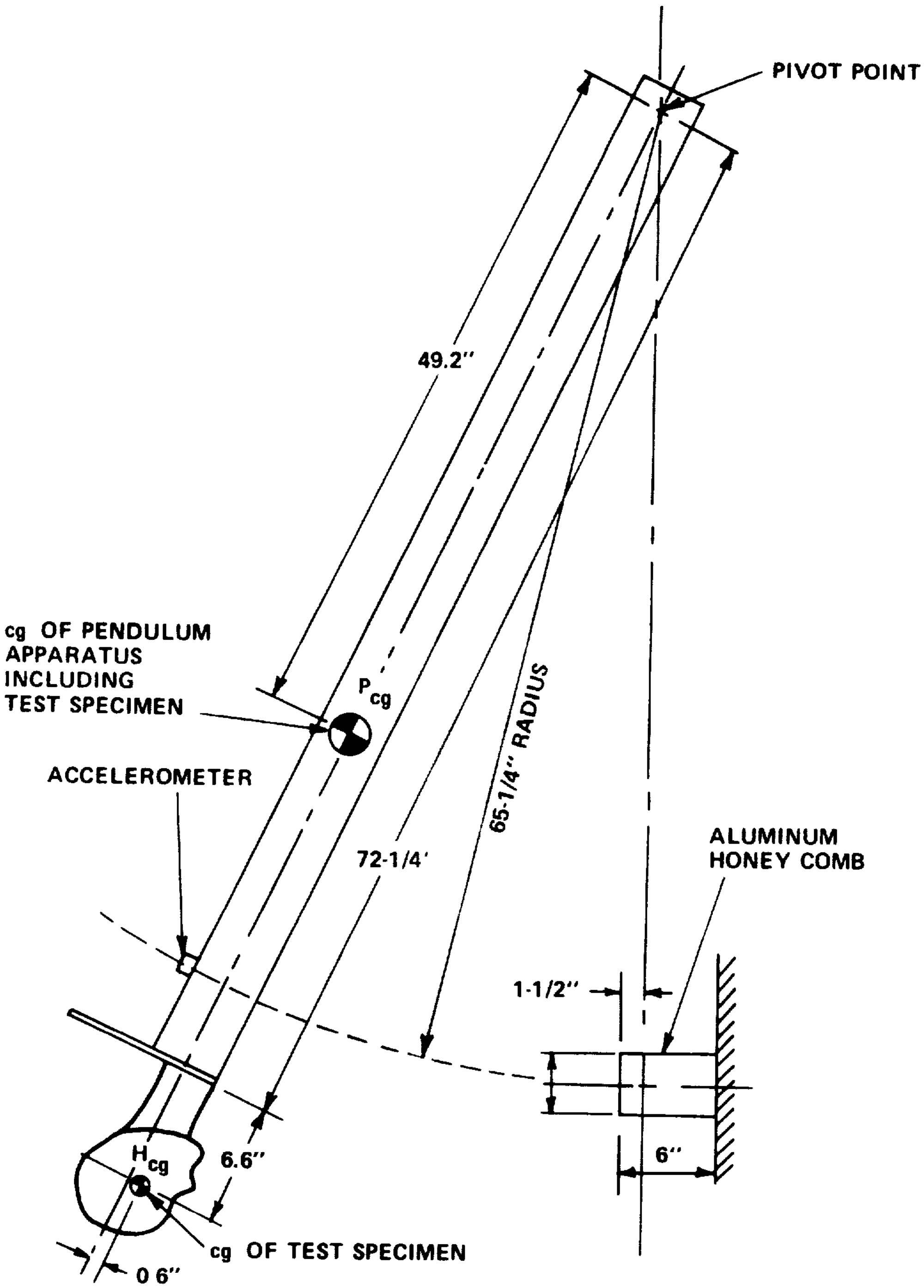


Figure 13 PENDULUM DIMENSIONS

TABLE 7

SPECIFICATIONS OF ALUMINUM HONEYCOMB ENERGY ABSORBING PENDULUM STOP

Manufacturer:	HEXCELL
Specify:	Hexcell-3000
Material:	Aluminum Alloy-3003
Gauge:	0.0028"
Density:	1.8 lbs/ft^3
Cell Size:	3/4"
Depth:	6" $\pm$0.062"
Width:	7 Complete Cells ($\approx$ 4")
Length:	12"

TABLE 8

INERTIAL PROPERTIES OF THE ARRESTED PENDULUM

Configuration	Weight Lbs.	Distance from CG to Pendulum Pivot Axis (In.)	Mass Moment of Inertia About Pivot Axis ($Lb/Ft/Sec^2$)
Pendulum Only	56.9	40	27.4
Pendulum plus lead/Neck	74.4	49.2	51.7

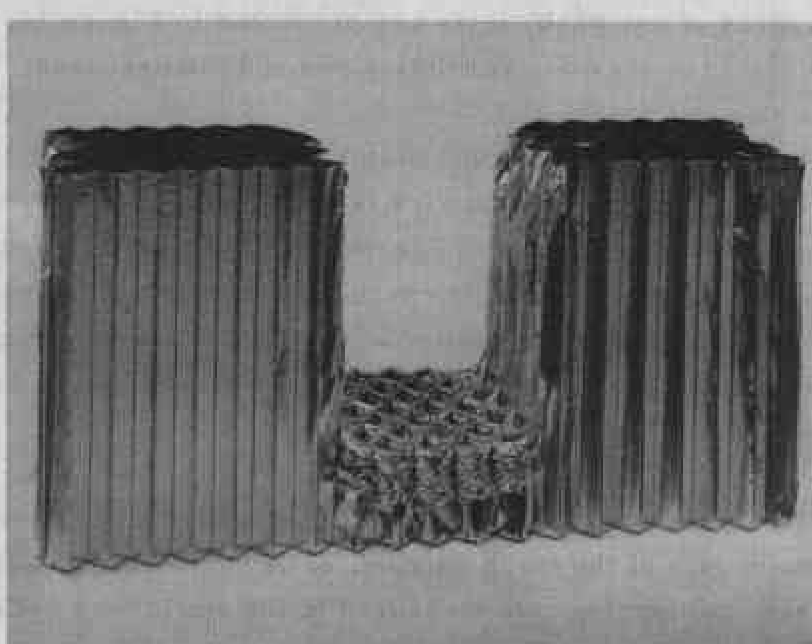


Figure 14 ALUMINUM HONEYCOMB ENERGY ABSORBER FOR ARRESTED PENDULUM — TYPICAL SAMPLE SHOWING CRUSH AFTER USE

head and pendulum accelerations were recorded, and high speed motion pictures were taken for each test. The head was instrumented with a Kistler Model 833 (serial number 937) triaxial accelerometer having a range of 750 g's and the pendulum was instrumented with a Bell & Howell Model 09384-4-202-001 (serial number 17931) single axis accelerometer having a 250 g range. A tape switch was attached to the face of the aluminum honeycomb pendulum arrestor to indicate the time of initial impact. Sequence pictures of one of the tests are presented in Figure 15. The timing clock shown makes one revolution per 100 milliseconds.

The head displacement histories, Figures 16 and 17, were determined from the high speed movies taken of each run. The recorded test acceleration data are shown in Figure 18. The displacements and accelerations measured for this 95th percentile dummy were approximately the same in peak amplitude, frequency of oscillation and damping as were measured on the 50th percentile dummy with the Sierra single durometer rubber neck.

This measurement was performed with the neck assembly free from the dummy skin of the torso section, believed to be the cause of the stiffer than expected spring rate measured in the static load deflection tests, and therefore is not fully representative of the dynamic response to be expected with the fully assembled dummy. A more representative measure of the actual dynamic neck characteristics can be obtained by analyzing the motion picture films of head/neck displacements resulting from the test series of pendulum impacts to the chest of the assembled dummy.

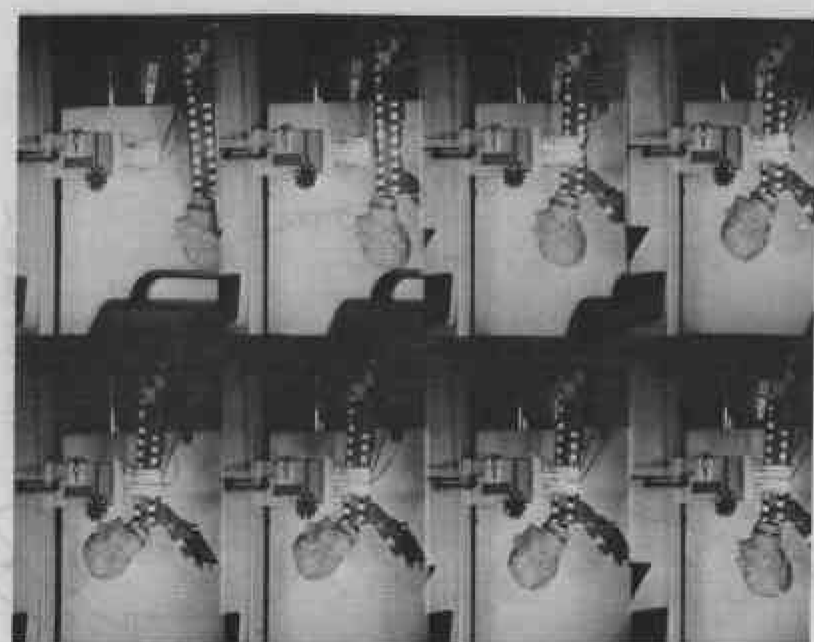


Figure 15 RESPONSE OF THE SIERRA MODEL 292-1295 HEAD NECK

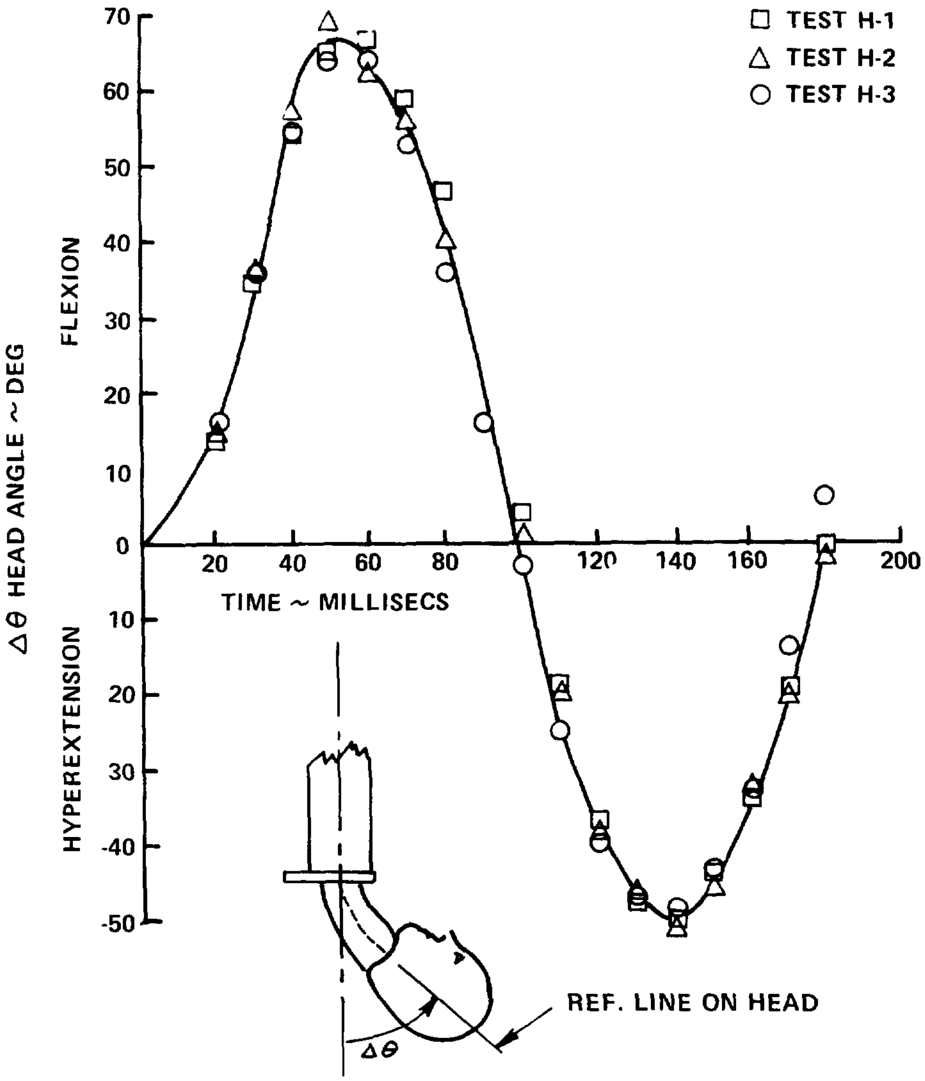


Figure 16 HEAD ANGULAR DISPLACEMENT HISTORY IN ARRESTED PENDULUM TESTS OF SIERRA MODEL 292-1295 DUMMY HEAD/NECK

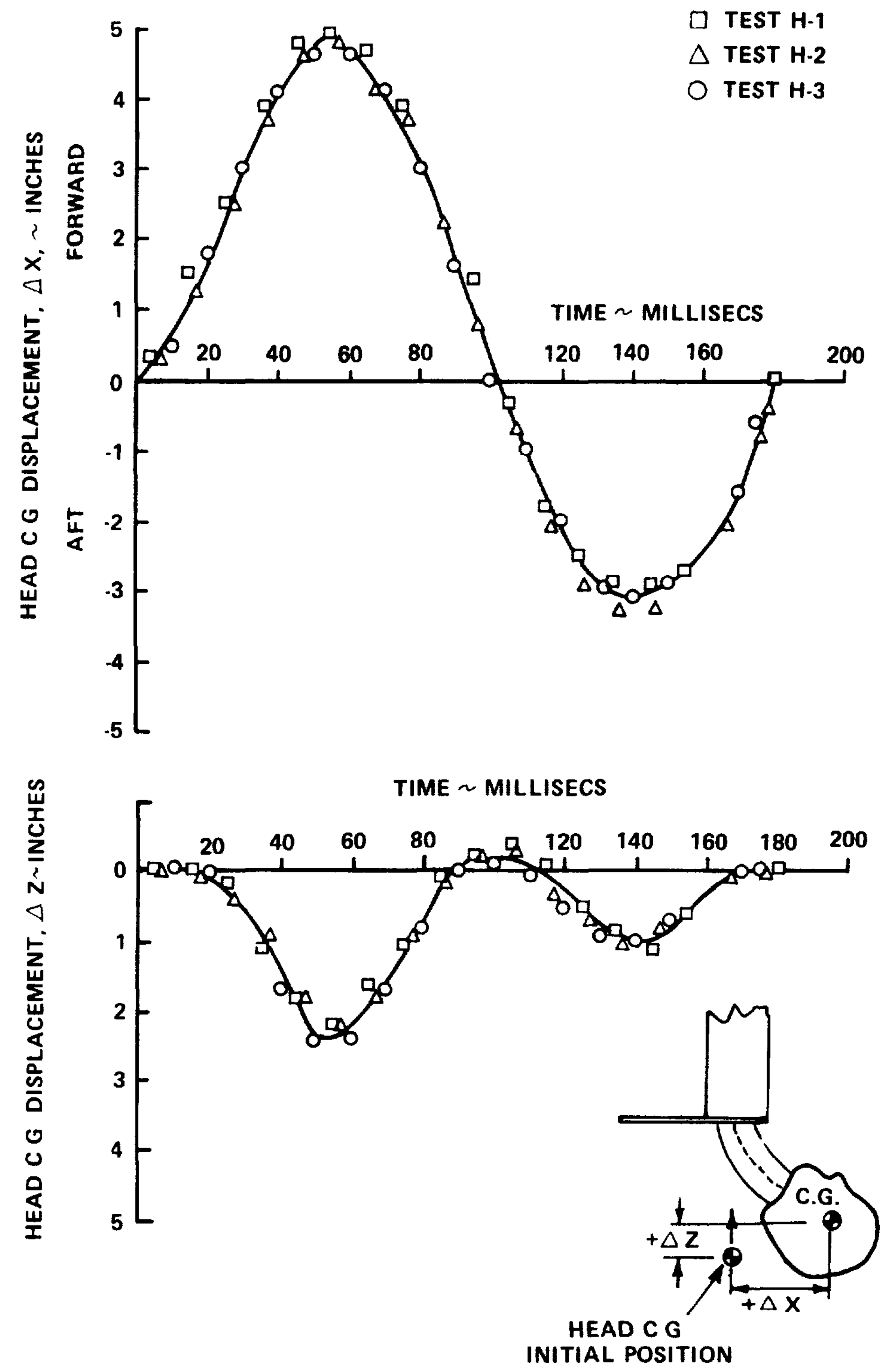
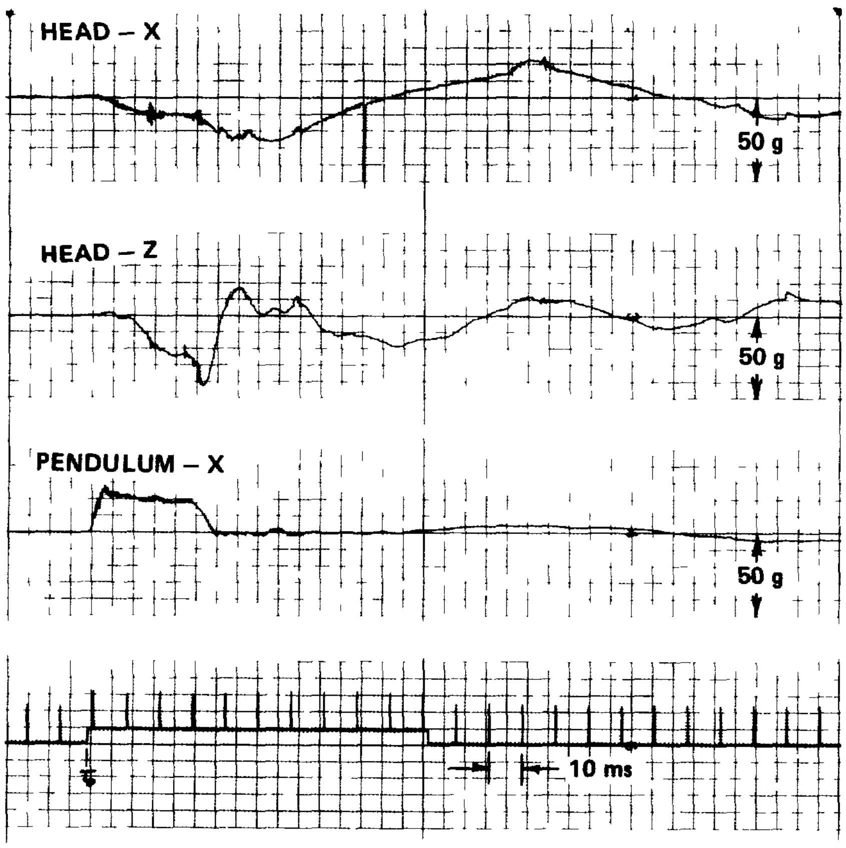
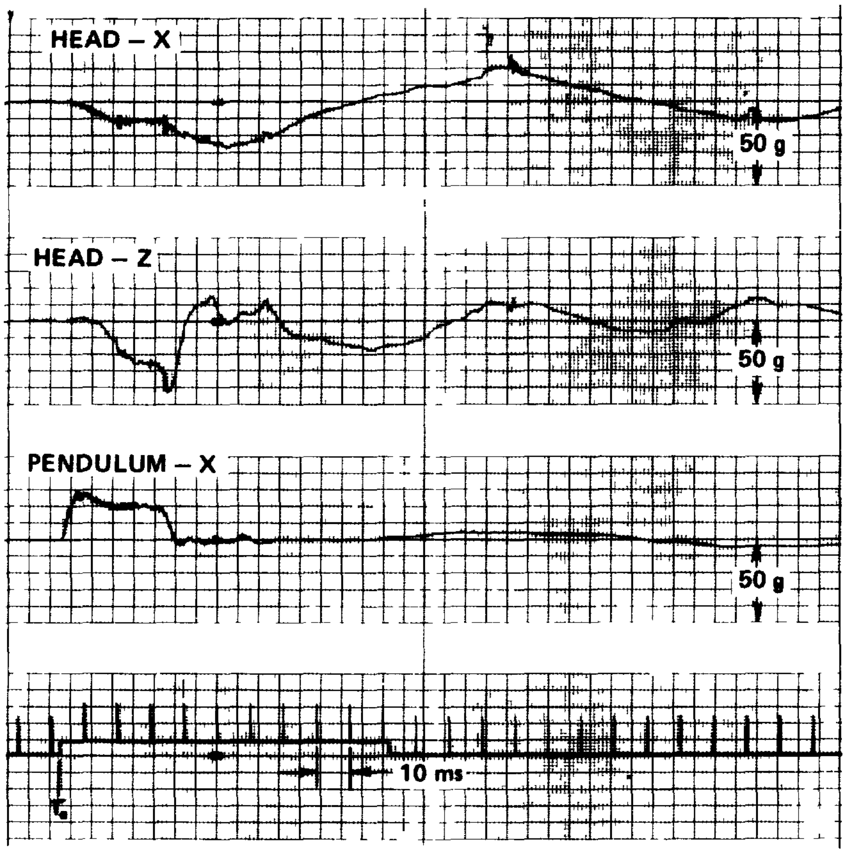


Figure 17 HEAD C.G. DISPLACEMENT HISTORY IN ARRESTED PENDULUM TESTS OF SIERRA MODEL 292-1295 DUMMY HEAD/NECK



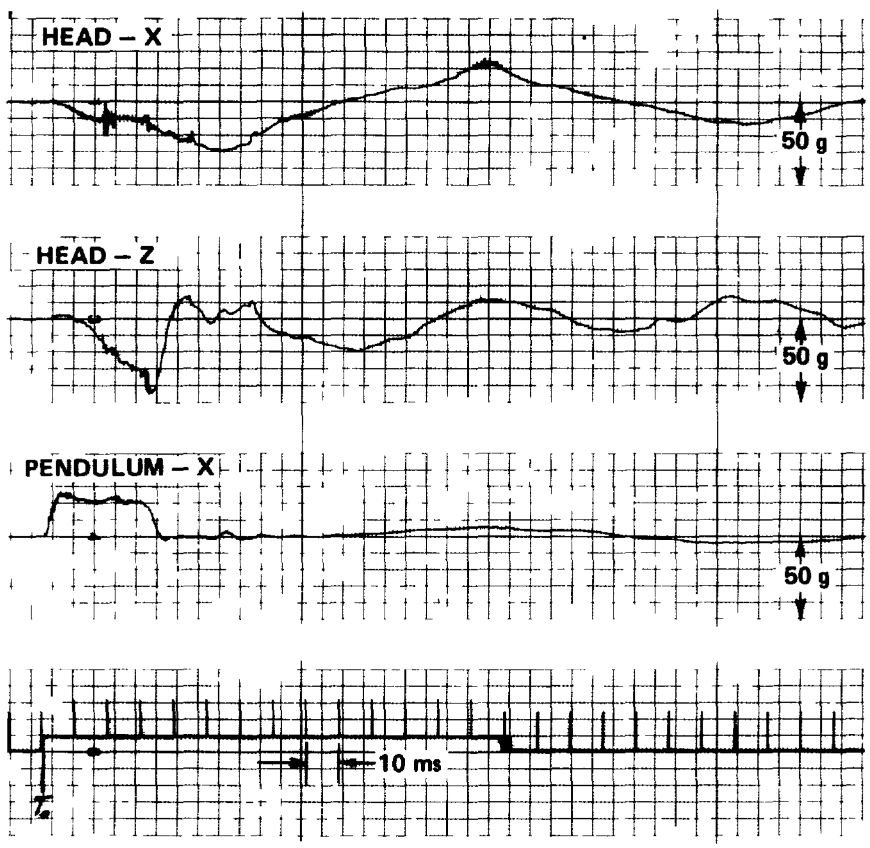
(a) FIRST OF THREE REPEATS

Figure 18 HEAD/NECK PENDULUM TESTS OF THE SIERRA MODEL 292-1295 WOOD HEAD AND SINGLE DUROMETER RUBBER NECK



(b) SECOND OF THREE REPEATS

Figure 18 (Cont'd.)



(c) THIRD OF THREE REPEATS

Figure 18 (Cont'd.)

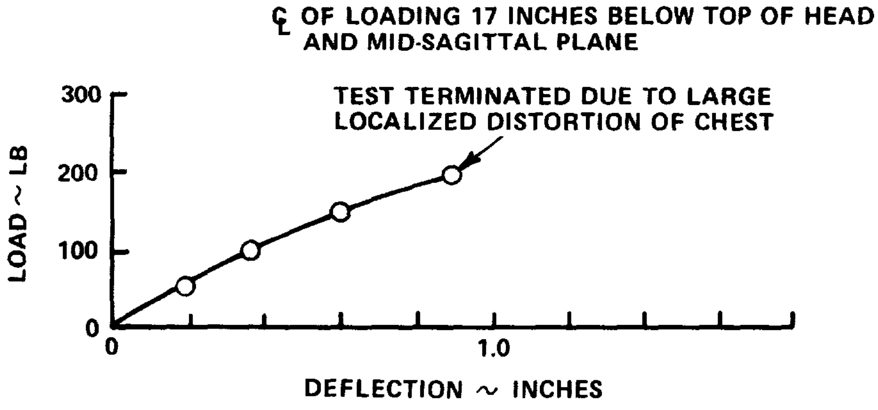
4.5 Static Load-Deflection of the Chest Assembly (Task 4a)

The following procedure* was required for the measurement of the static load-deflection characteristics for the chest of the 95th percentile dummy:

1. A rigid test probe having a flat circular face six inches in diameter and edge radius of 1/2 inch shall be used.
2. The face of the test probe shall be parallel to the test surface.
3. The test dummy shall be firmly supported at its back.
4. Rate of probe penetration shall not exceed one inch per minute.
5. Chest load-deflection characteristics shall be determined at the sternum in the mid-sagittal plane 16 and 20 inches below the top of the head, and at location 20 inches below the top of the head, three inches from the mid-sagittal plane. In each instance, the test shall be terminated when a deflection of three inches or the yield point of the chest is reached.

The magnitude of the applied load force could be read to ± 5 lbs. and the chest deflection to $\pm 1/16$ of an inch. The resulting force deflection properties are shown in Figure 19. In comparison with the results obtained from static chest deflection tests on the 50th percentile dummies, this chest is relatively "soft". An average spring constant of 200 lb./in. was measured as opposed to the 1000 lb./in. spring constant for the 50th percentile modified Alderson chest. In addition, 0.6" of hysteresis was measured upon return to zero from a 300 lb. load.

*As stated in the contract.



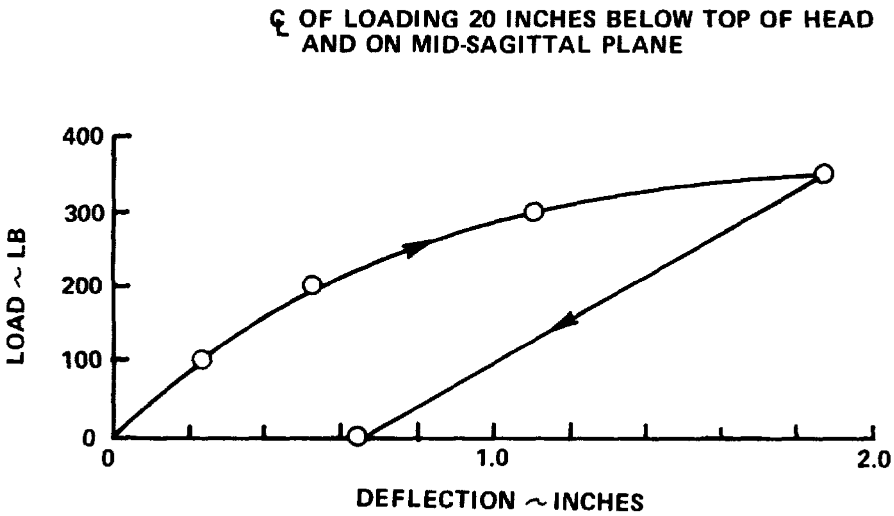


Figure 19 STATIC LOAD/DEFLECTION OF SIERRA MODEL 292-1295 DUMMY CHEST

Results for the case in which centerline of the load was applied 20 inches below the top of the head and 3 inches to one side of the mid-sagittal are not presented because large localized deformations occurred for a relatively small load and it was believed that further loading might permanently damage the structure.

4.6 Pendulum Impact at the Chest of the Assembled Dummy (Task 4b)

The following procedure was required for measuring the dynamic load-deflection characteristics for the chest of the 95th percentile dummy at impact velocities of 14 ft/sec and 22 ft/sec with three impacts at each velocity:

1. The complete dummy is seated on a hard, horizontal surface, with its head, neck, and torso in the upright position, unsupported and unrestrained with the limbs extended horizontally in a forward position.
2. A rigid test probe having a flat circular face six inches in diameter and edge radius of 1/2 inch, weighing 50 lbs., including instrumentation, impacts the dummy's chest at designated speed in the anterior-posterior direction. During the impact, the probe is restrained without loss of energy from any other motion but translation in the dummy's anterior-posterior direction.
3. The chest is impacted at the point in mid-sagittal plane 20 inches below the top of the head, the probe face being parallel to the impact surface, its center coinciding with the specified impact point.
4. The time histories of the impact force, as measured by the load cell on the impactor, and of the deflection of impact point relative to the dummy's back (spine) is recorded and force-deflection curve of the entire event plotted.
5. Chest damping is determined as a ratio of the area bounded between loading and unloading portions of the force-deflection curves and the total area under the loading curve.

` As stated in the contract.

The pendulum was instrumented with a Bell and Howell Model 09384-4-202-001 (serial number 17931) single axis accelerometer having a 250G range for measurement of the time history of pendulum deceleration which was converted to impact force by multiplying by the mass of the pendulum. A Kistler Model 833 (serial number 940) triaxial accelerometer with a range of 750G was installed in the dummy to measure the chest acceleration response. The deflection of the dummy chest was determined from the output of the chest deflection potentiometer already provided in the dummy by the manufacturer. The impacts were also photographed with a high speed movie camera. Figure 20 shows the test configuration and an impact sequence.

The time history records of dummy chest accelerations and deflections and of the pendulum acceleration obtained in three replicate tests for which the impact speed was 14 ft./sec., and in four replicate tests conducted at 22 ft./sec. impact velocity, are presented in Figures 21 and 22.

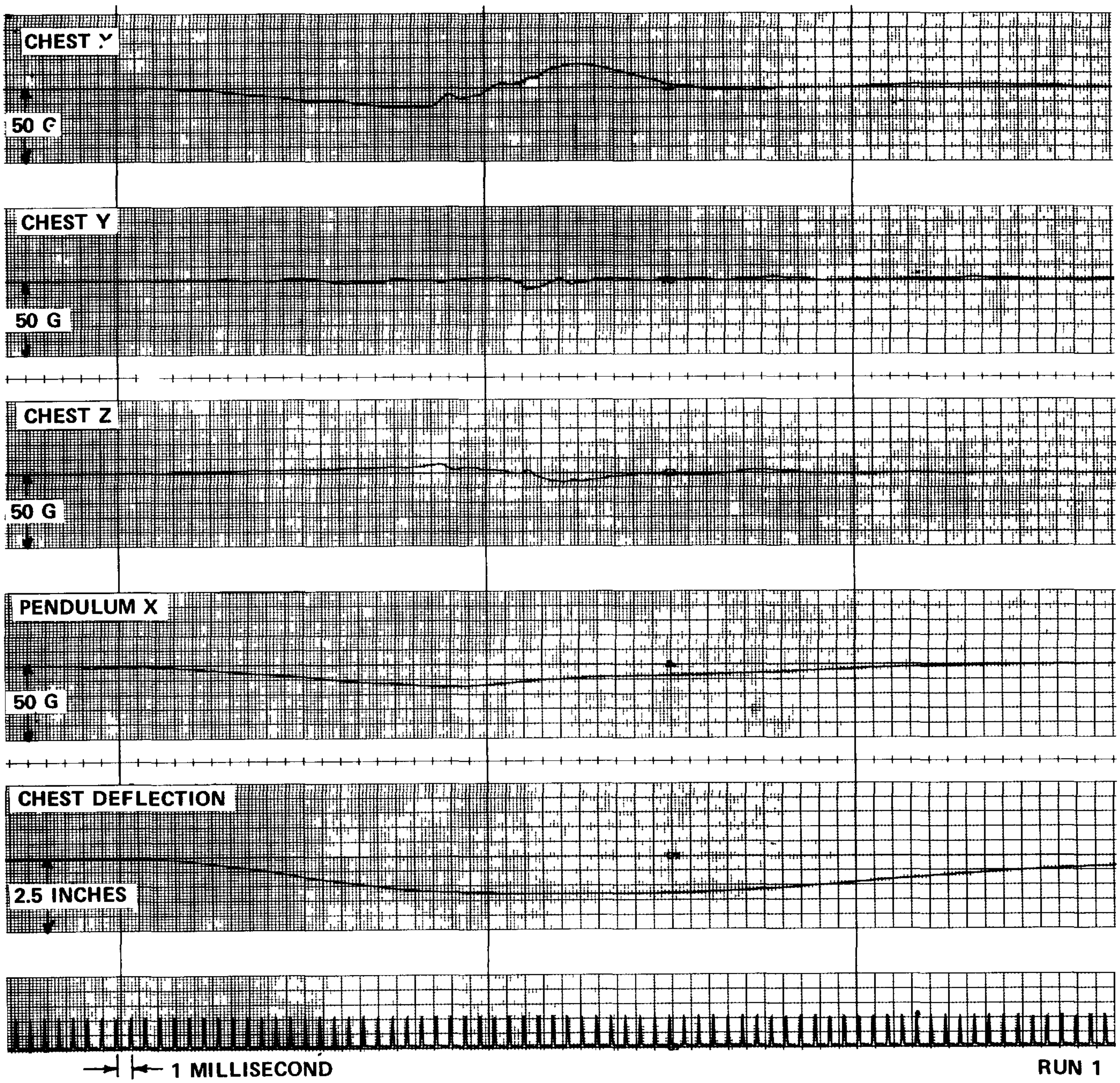
The recorded data is plotted as force versus deflection in Figures 23 and 24 for each of the impact tests. The peak force and peak deflection values are nearly the same as obtained in previous tests of the 50th percentile dummy chests, however, the shapes of the plots are much different. The initial slope of the curve is not as steep, indicating soft spring and low inertial forces; the curve increases to a peak without reversing, again indicating low initial inertial forces, and the three low-level impact tests have progressively smaller deflections, indicating a hysteresis or permanent set property. Multiple structural yields are indicated at the maximum force levels of the first two high level impacts. The last two curves are rather well defined, indicating that conditions may have stabilized for that particular test condition.

The damping of the chest structure, defined as the ratio of the area between the loading and unloading portions of the force-deflection curves and the total area under the loading curve, is given in Table 9 for each of the seven tests.

a. DUMMY CONFIGURATION FOR CHEST PENDULUM TESTS

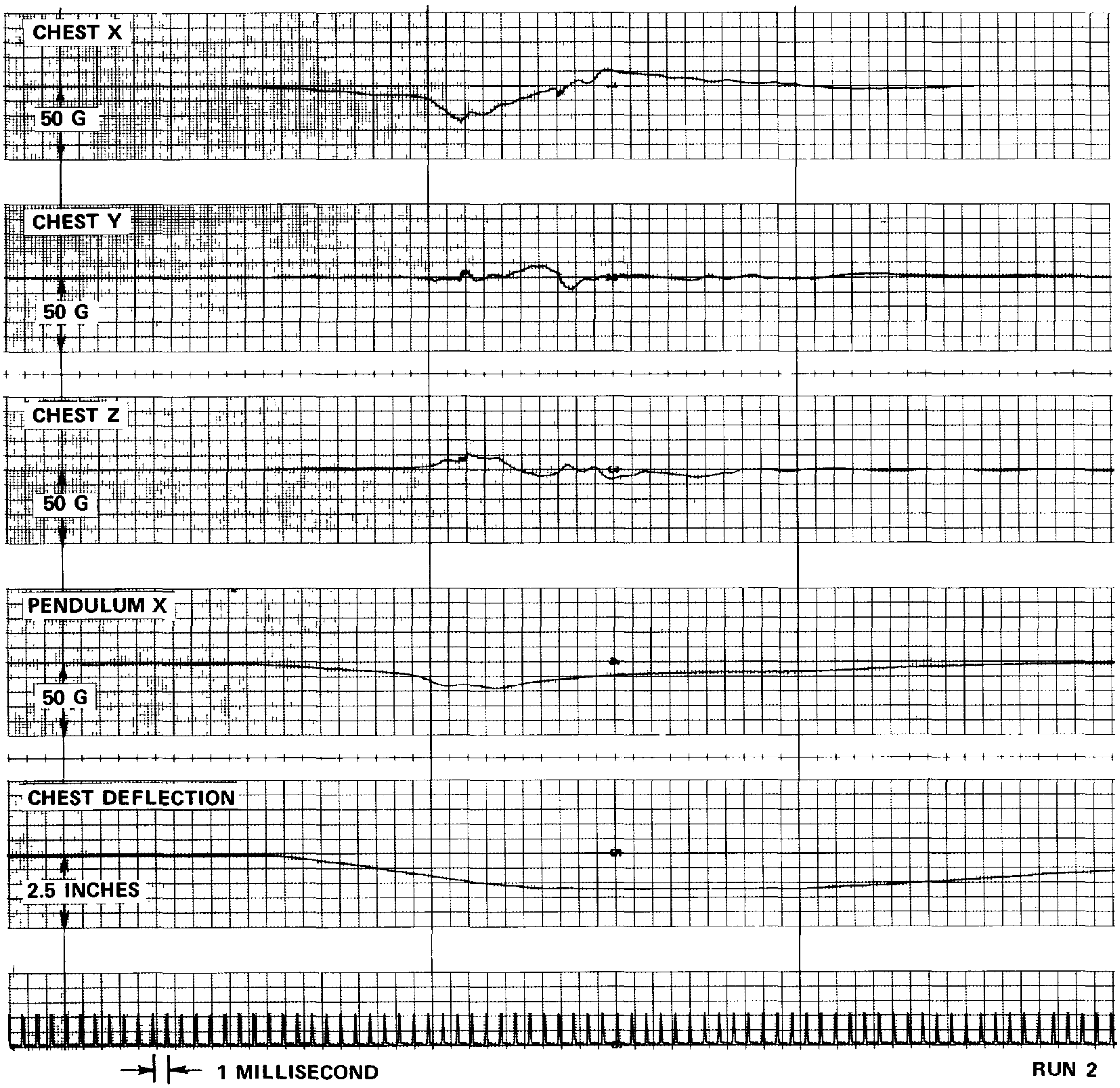
b. CHEST/PENDULUM TEST IMPACT SEQUENCE

Figure 20 IMPACT TEST OF SIERRA MODEL 292-1295 DUMMY CHEST



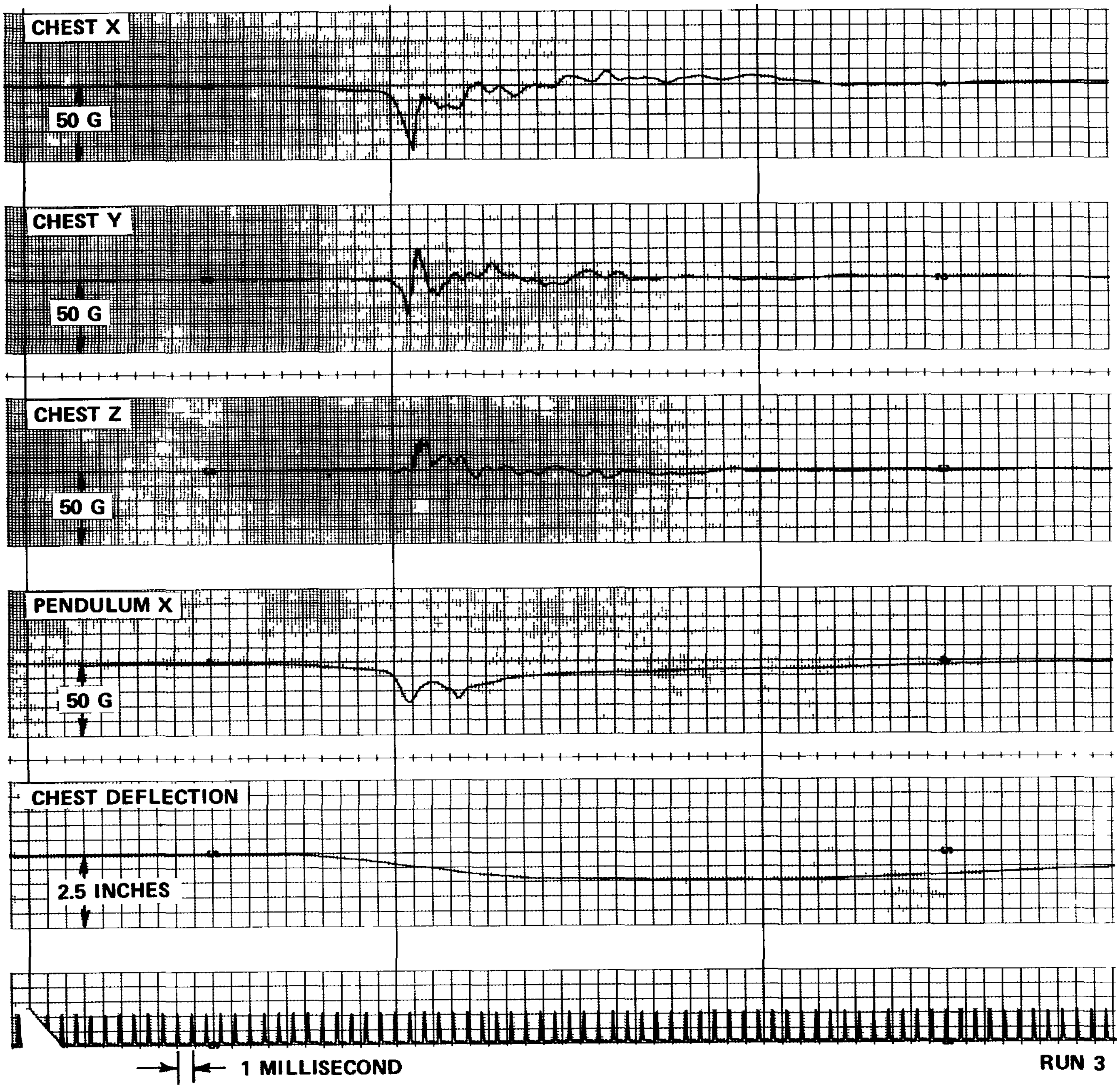
(a) FIRST OF THREE REPEATS

Figure 21 CHEST RESPONSE OF A SIERRA MODEL 292-1295 DUMMY TO THE 52 LB PENDULUM STRIKING THE CHEST AT 14 fps



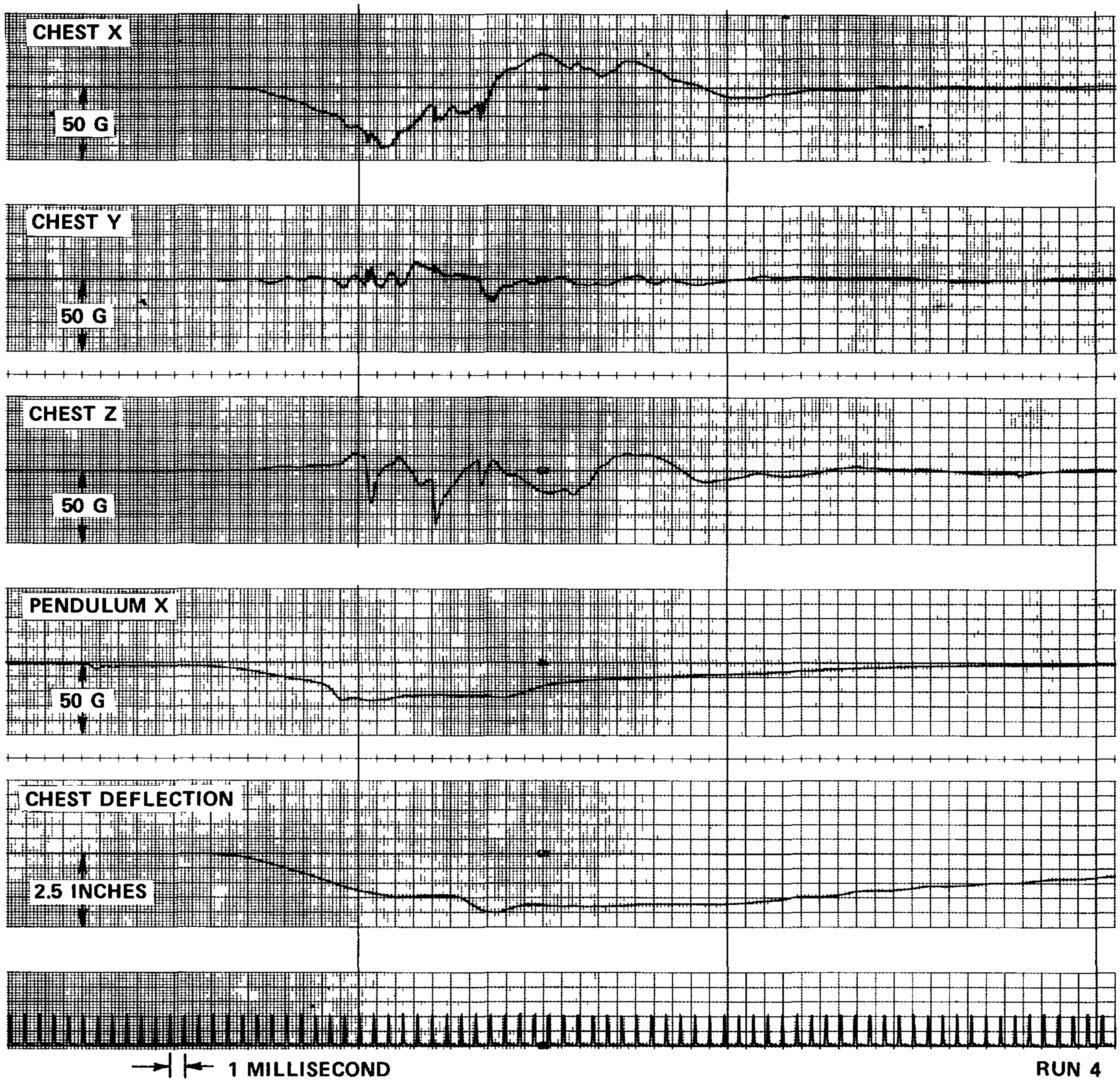
(b) SECOND OF THREE REPEATS

Figure 21 (Cont'd.)



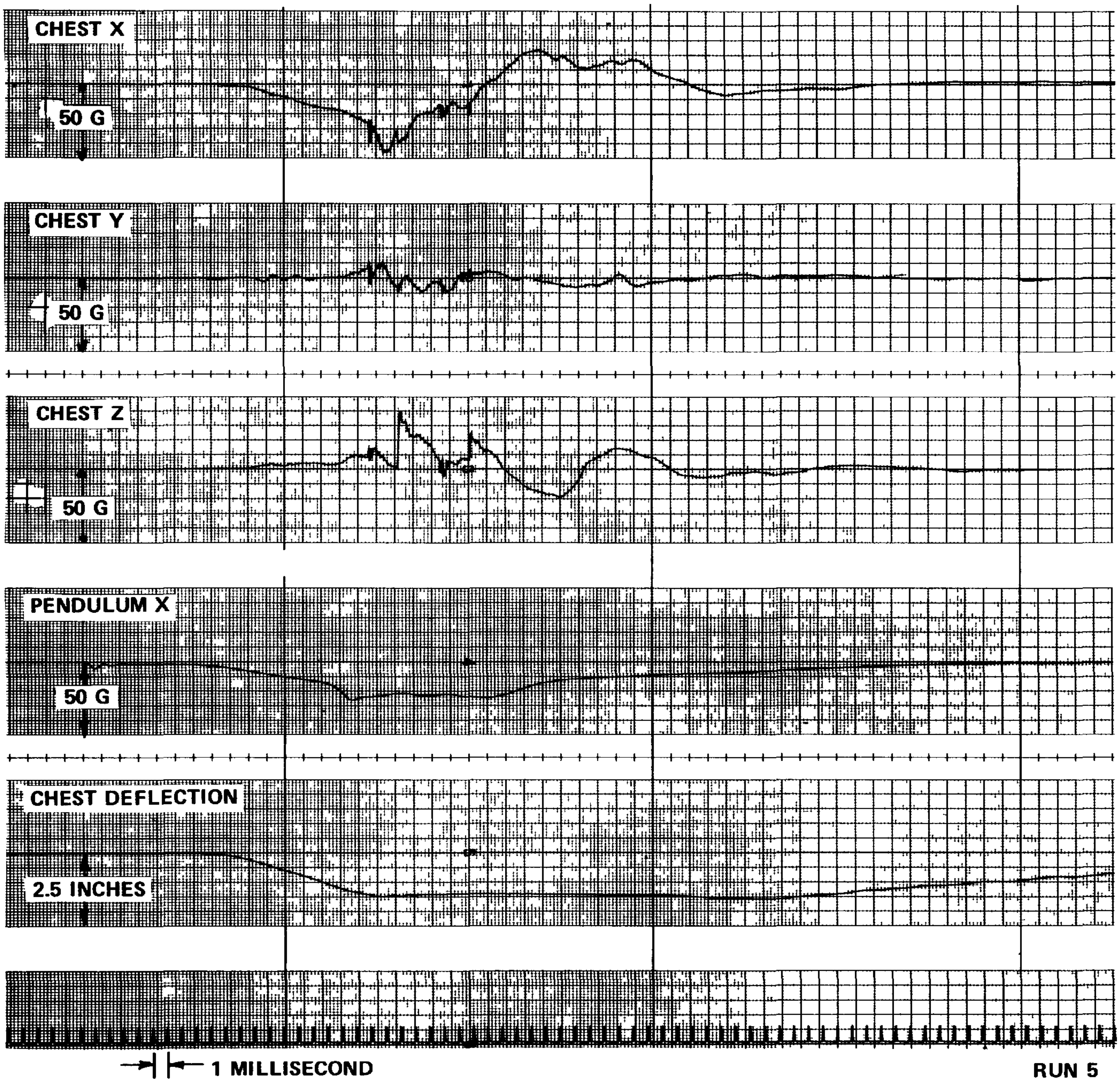
(c) THIRD OF THREE REPEATS

Figure 21 (Cont'd.)



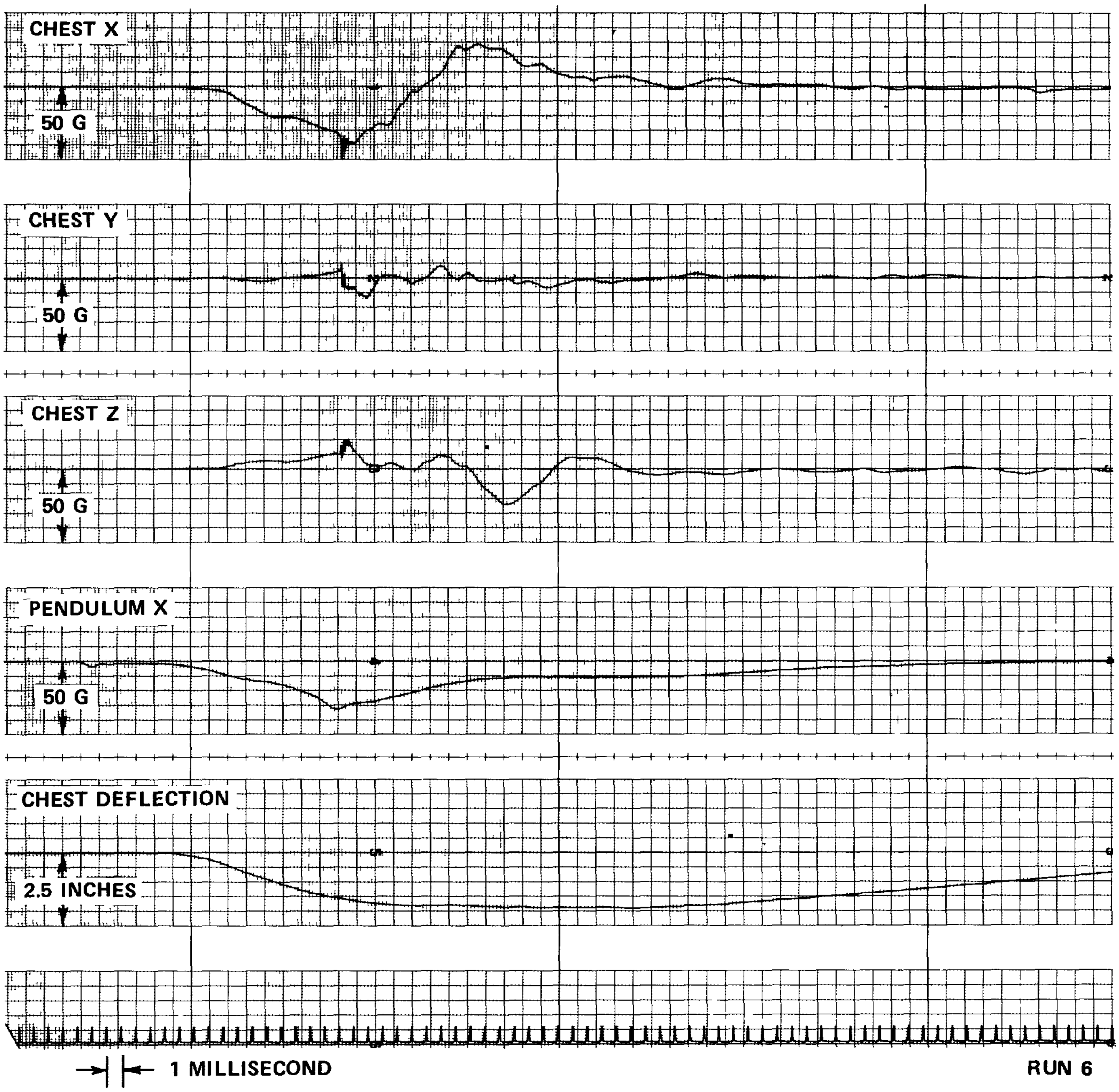
(a) FIRST OF FOUR REPEATS

Figure 22 CHEST RESPONSE OF A SIERRA MODEL 292-1295 DUMMY TO THE 52 LB PENDULUM STRIKING THE CHEST AT 22 fps



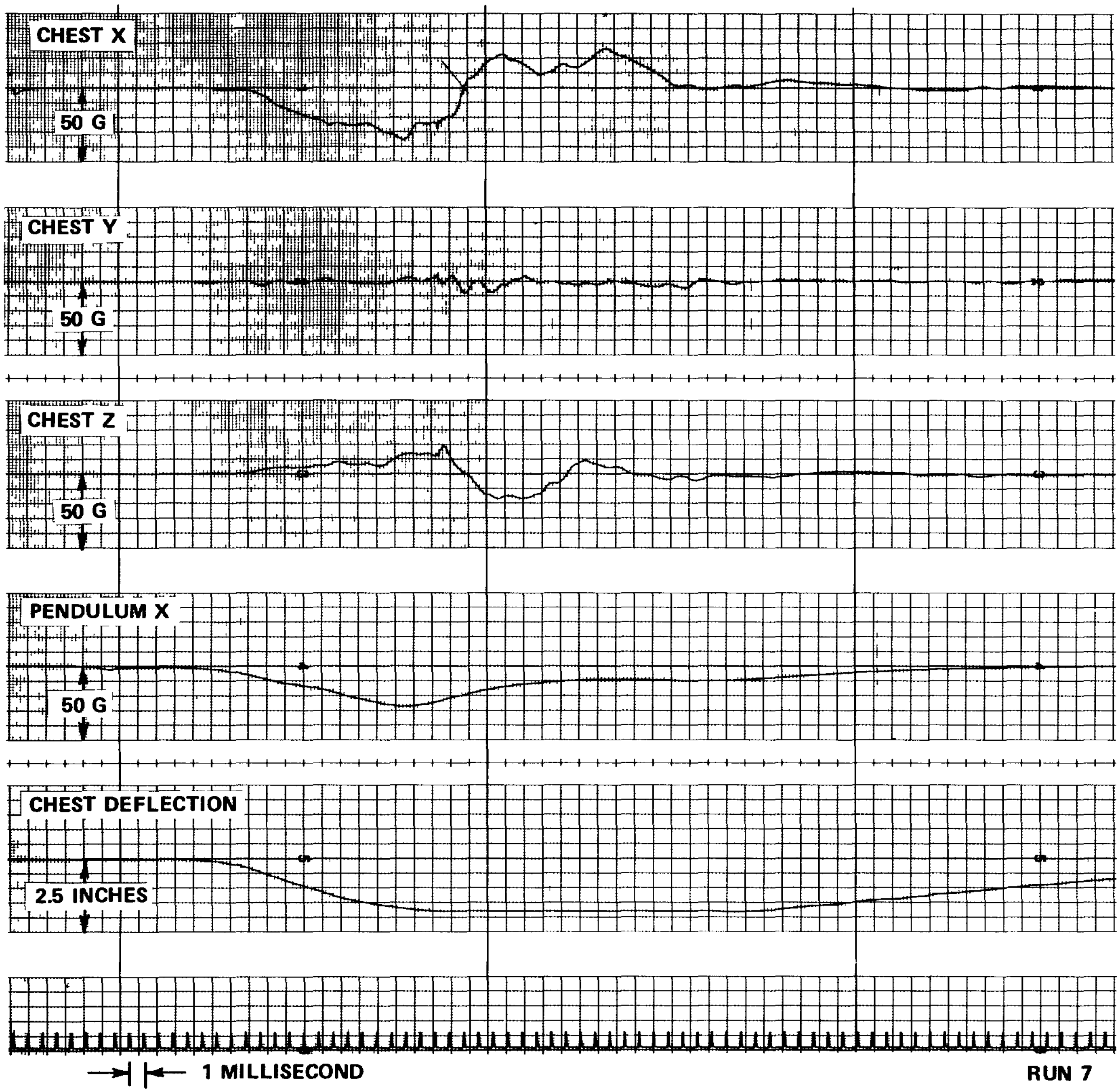
(b) SECOND OF FOUR REPEATS

Figure 22 (Cont'd.)



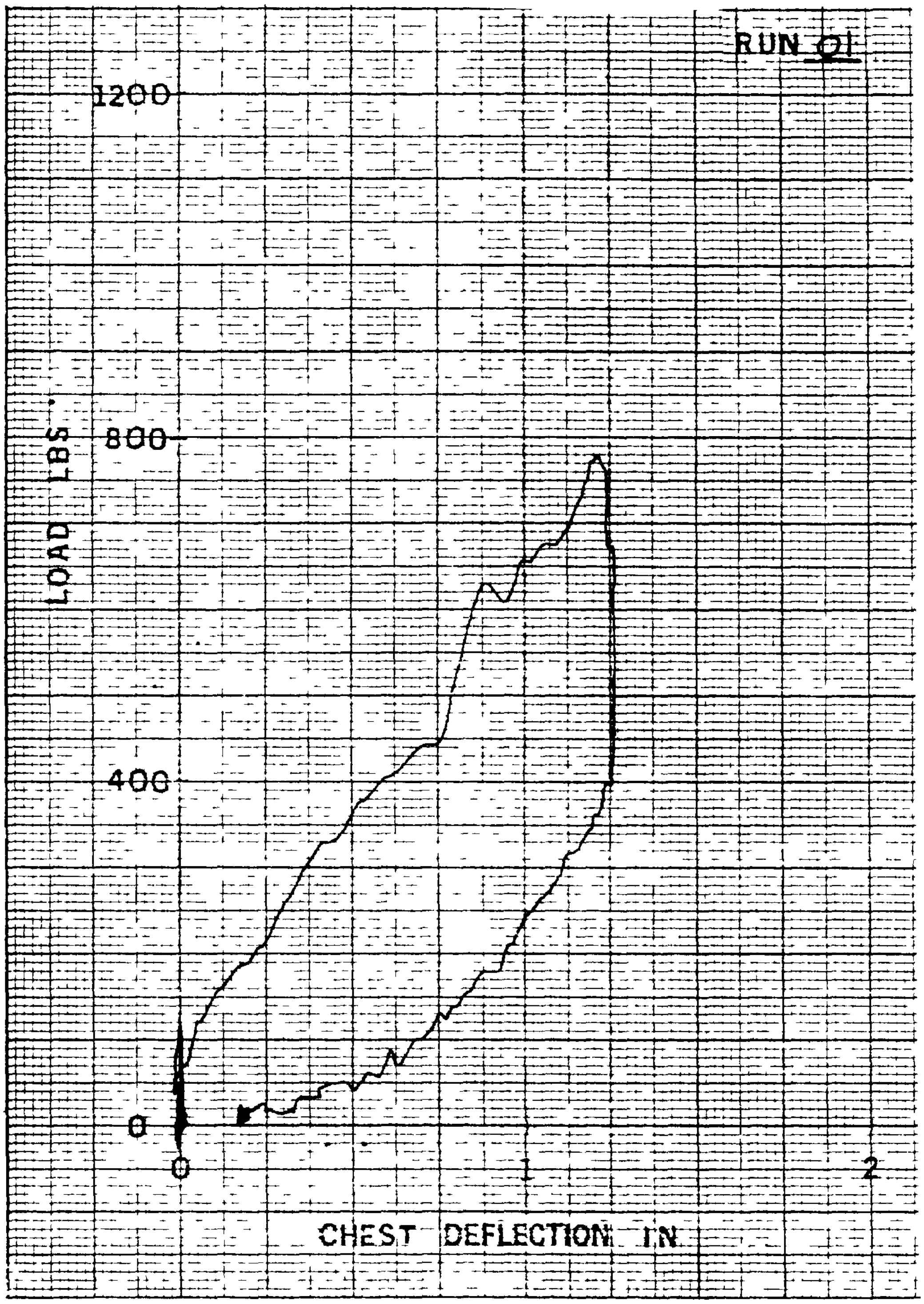
(c) THIRD OF FOUR REPEATS

Figure 22 (Cont'd.)



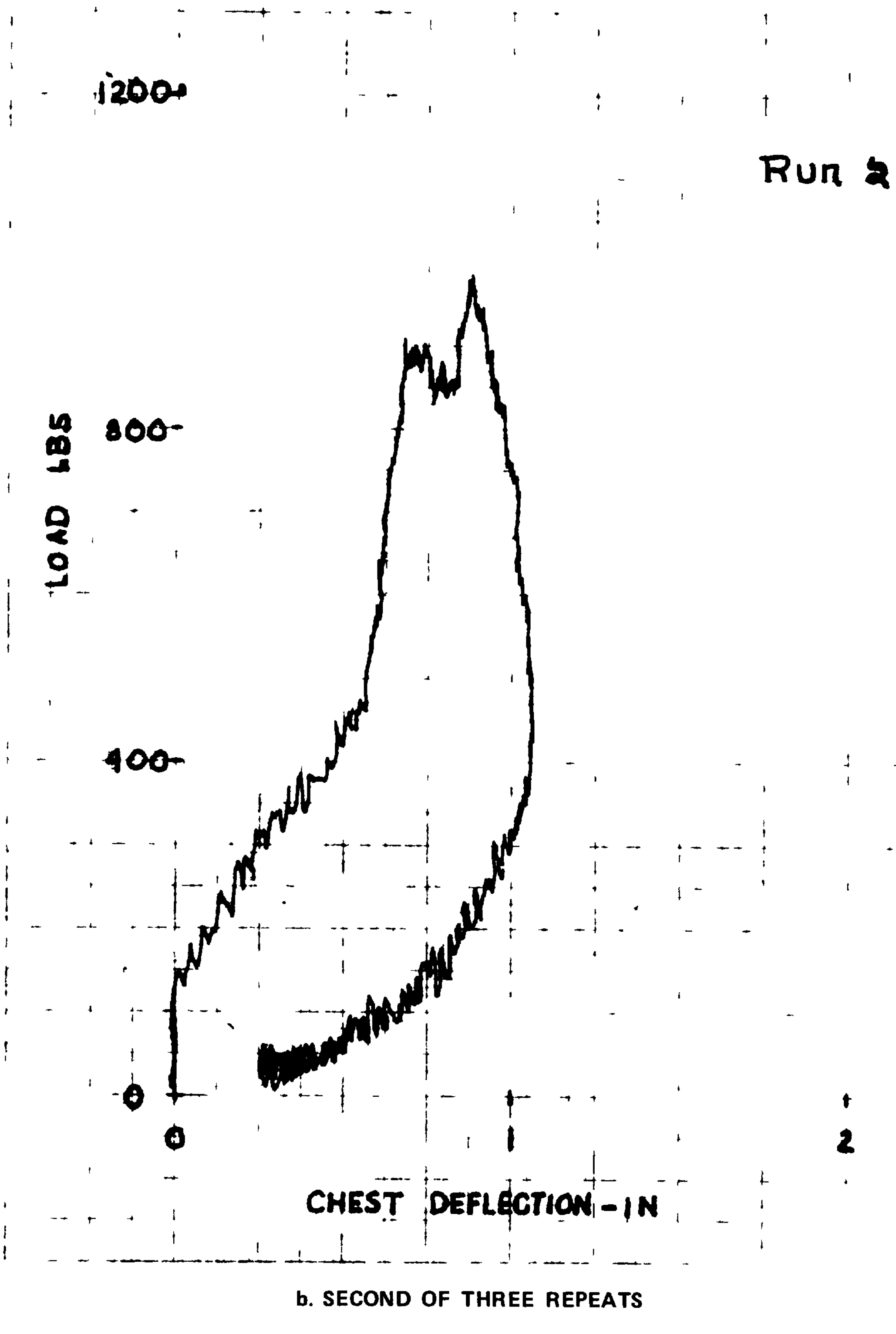
(d) FOURTH OF FOUR REPEATS

Figure 22 (Cont'd.)



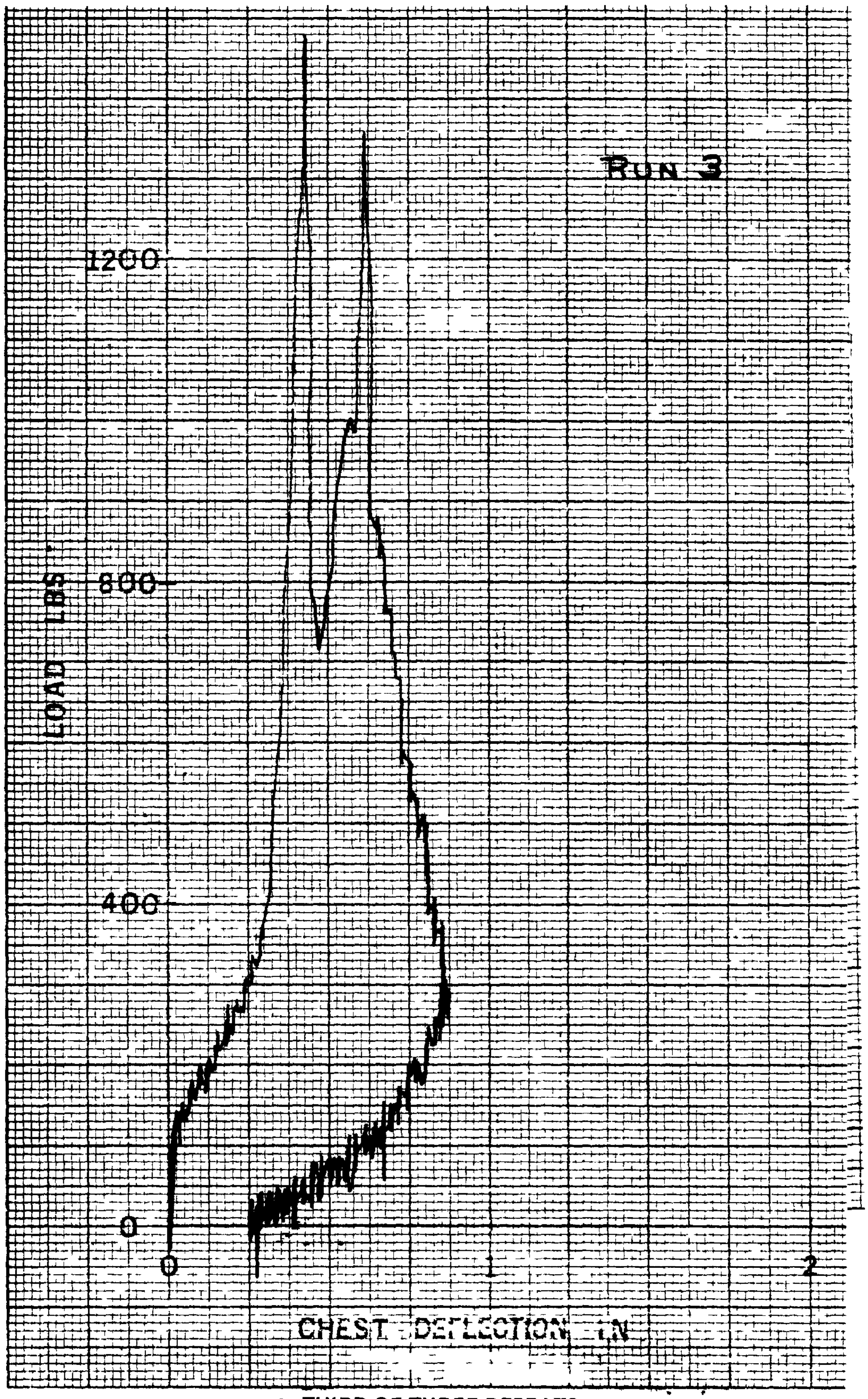
a FIRST OF THREE REPEATS

Figure 23 FORCE/DEFLECTION RESPONSE OF A SIERRA MODEL 292-1295 CHEST DUE TO A 52 LB PENDULUM STRIKING THE CHEST AT 14 fps.



b. SECOND OF THREE REPEATS

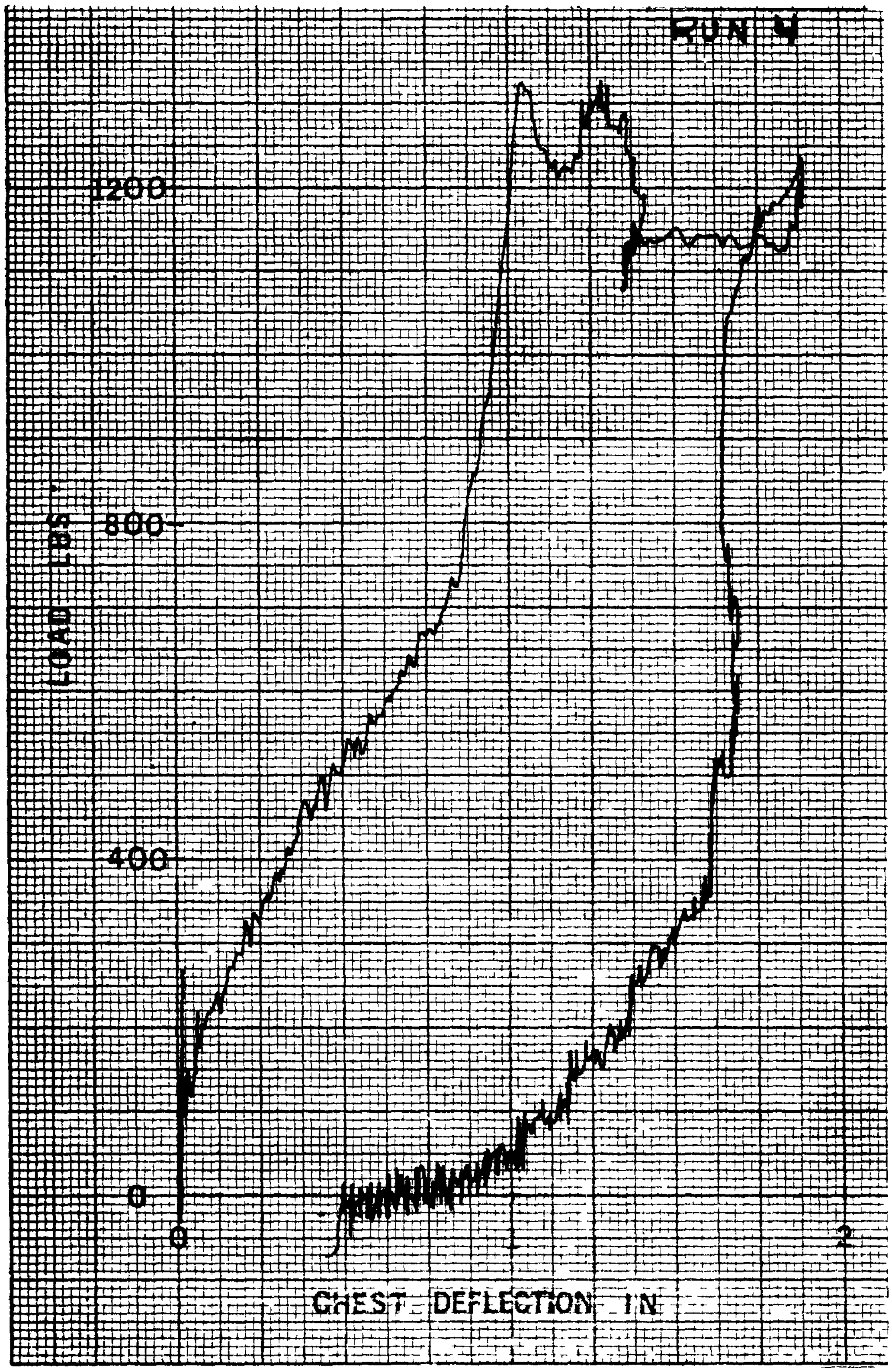
Figure 23 (Cont'd.)



c. THIRD OF THREE REPEATS

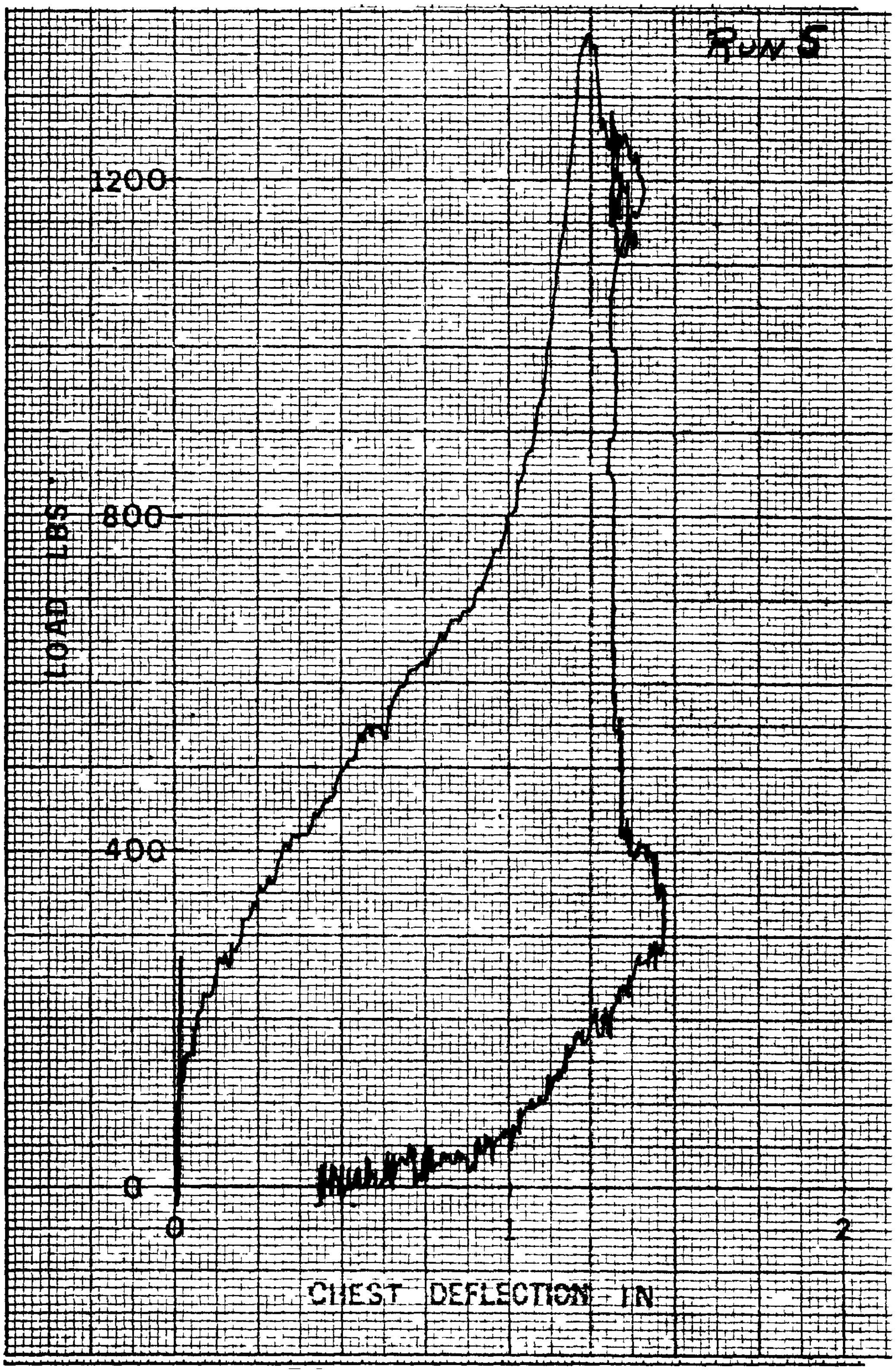
Figure 23 (Cont'd.)

FA-5018-V-3



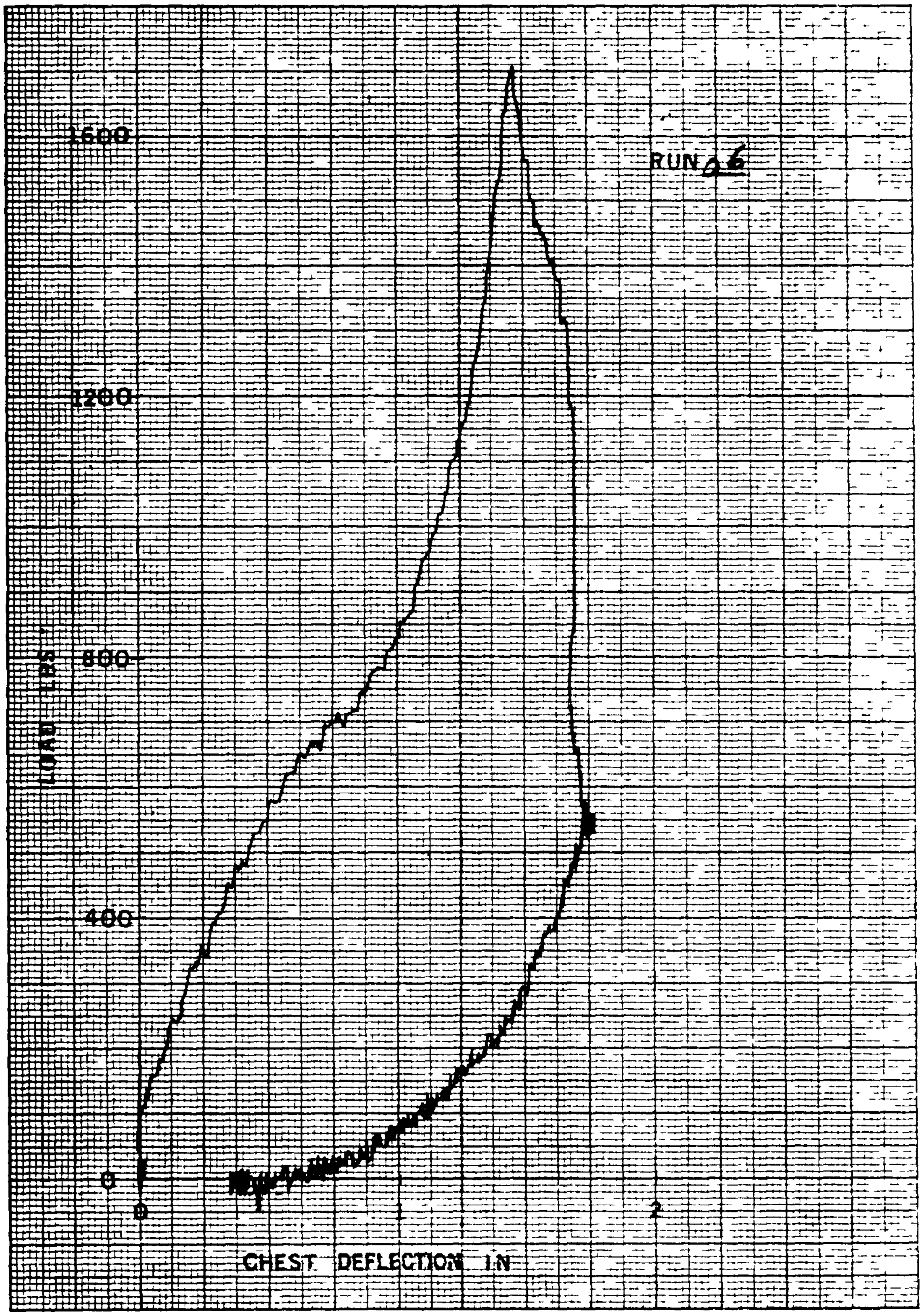
a. FIRST OF FOUR REPEATS

Figure 24 FORCE/DEFLECTION RESPONSE OF A SIERRA MODEL 292-1295 CHEST DUE TO A 52 LB PENDULUM STRIKING THE CHEST AT 22 fps.



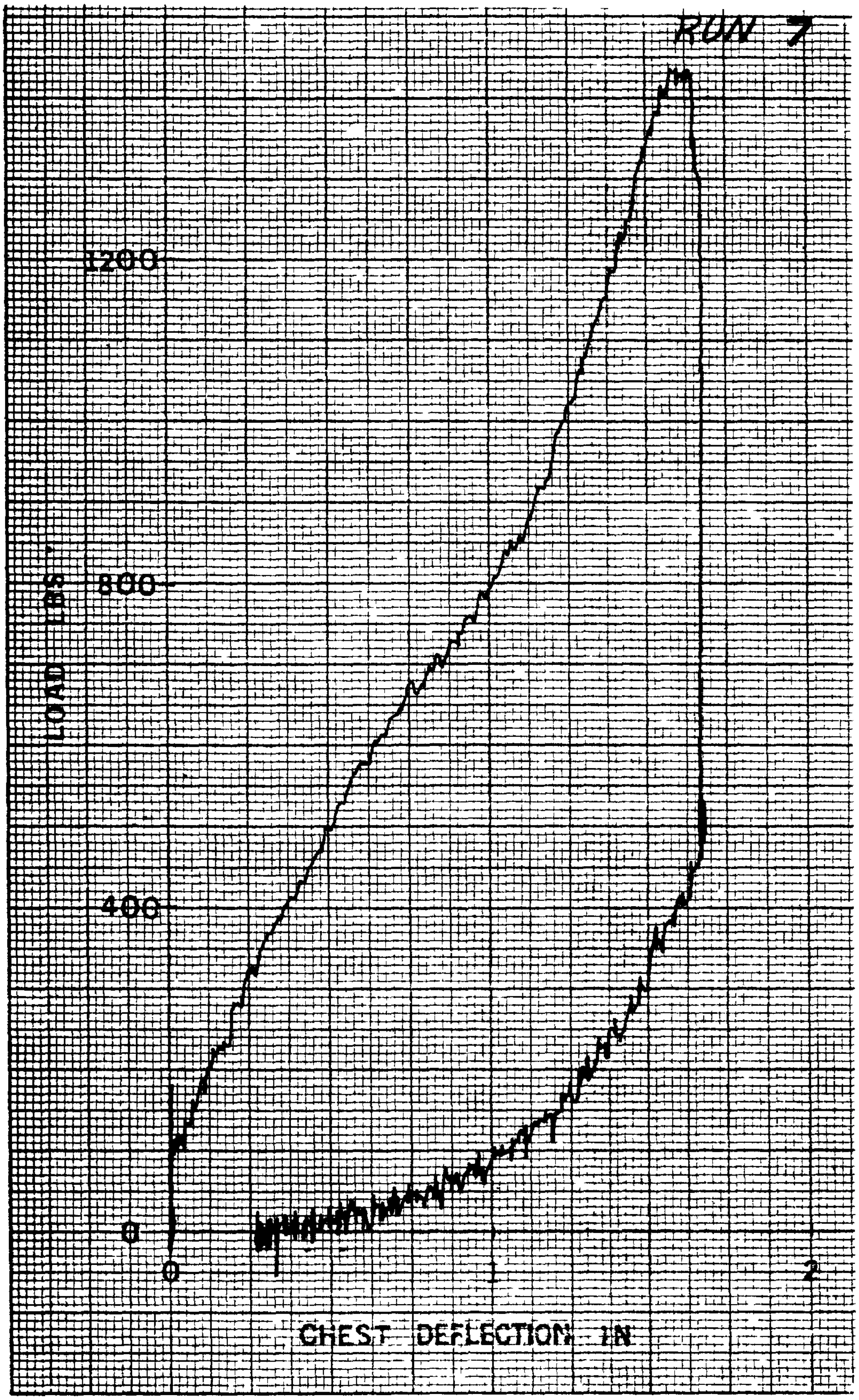
b. SECOND OF FOUR REPEATS

Figure 24 (Cont'd.)



c THIRD OF FOUR REPEATS
(NOTE CHANGE IN SCALES)

Figure 24 (Cont'd.)



d. FOURTH OF FOUR REPEATS

Figure 24 (Cont'd.)

TABLE 9

CHEST DAMPING OF SIERRA MODEL 292-1295 DUMMY

Run No.	Impact Velocity	Work Done During Loading (In-Lbs)	Work Dissipated During Unloading (In-Lbs)	Chest Damping
1	14 fps	535	385	.72
2	14 fps	542	438	.81
3	14 fps	511	445	.87
4	22 fps	1313	1157	.88
5	22 fps	893	799	.89
6	22 fps	1383	1191	.86
7	22 fps	1204	1036	.86

4.7 Hyge Sled Simulation of the 30-MPH Barrier Impact with the Dummy in a 4-Point Belt Restraint (Task 5)

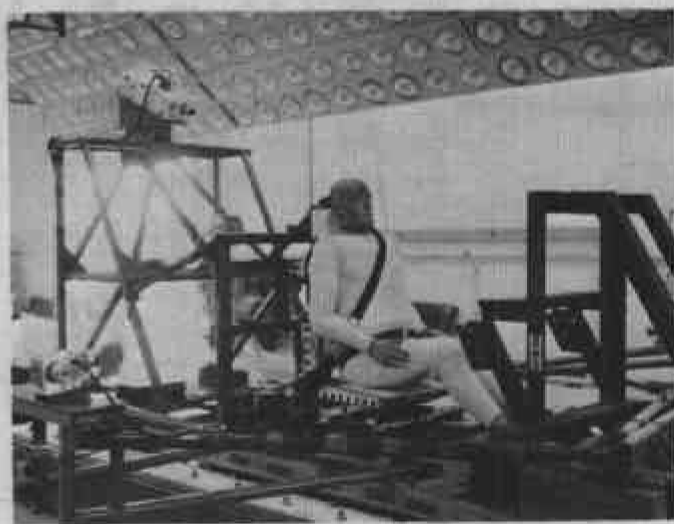
The requirements* for the measurement of the dummy dynamic response to sled simulation tests of a 30-mph barrier impact were simply to perform three tests using the Calspan standard test seat and a four-point restraint belt system preloaded to five pounds.

Photographs of the dummy before and after a test are shown in Figure 25. In these tests, the dummy was restrained by lap and shoulder belts and subjected to the same 30 MPH sled acceleration pulse as had been used in the previous tests of other dummies. The four-point restraint system included locking retractors, and the belts were each preloaded to approximately five pounds. The dummy was instrumented with Kistler Model 833 750-G triaxial accelerometers in the head and chest cavities. The potentiometer provided in the chest was used to measure the chest deflections and belt loads were measured by four Lebow force transducers.

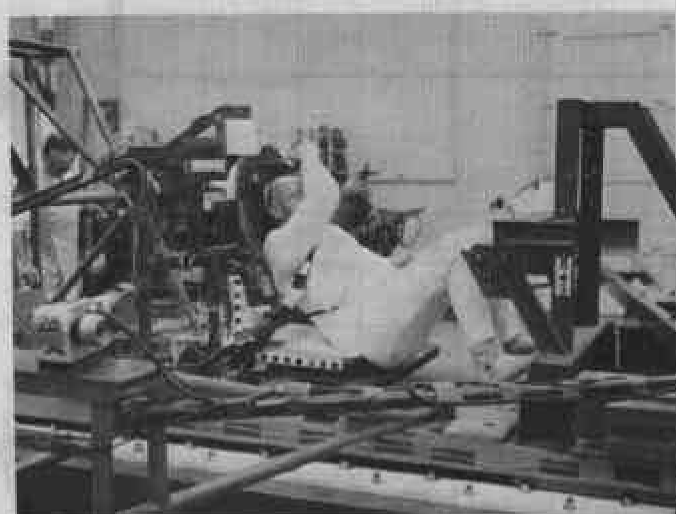
The dummy was prepared by setting all joints to 1-G and pivoting the neck 10 degrees forward from vertical. The neck and spinal column cable tensions were adjusted by tightening the nut on the neck cable by 1/4" from the zero load position, and similarly tightening the lumbar spine cable nut 1/2" from the zero load position. The dummy was carefully positioned for each run by placing it in the seat in exactly the same back, arm, leg and foot position, after placing a 6-inch diameter cylinder across the abdomen and applying a horizontal 50 pound force rearward on the cylinder while lifting the dummy by the shoulders into an erect seated position.

Computer plots of the data from the three repeated sled tests are presented in Figure 26. The Head Injury Criteria (HIC) and Head Severity Index numbers were computed for each test, and the three tests analyzed in terms of mean, standard deviation, and coefficient of variation, and are presented in table 10.

*As stated in the contract.

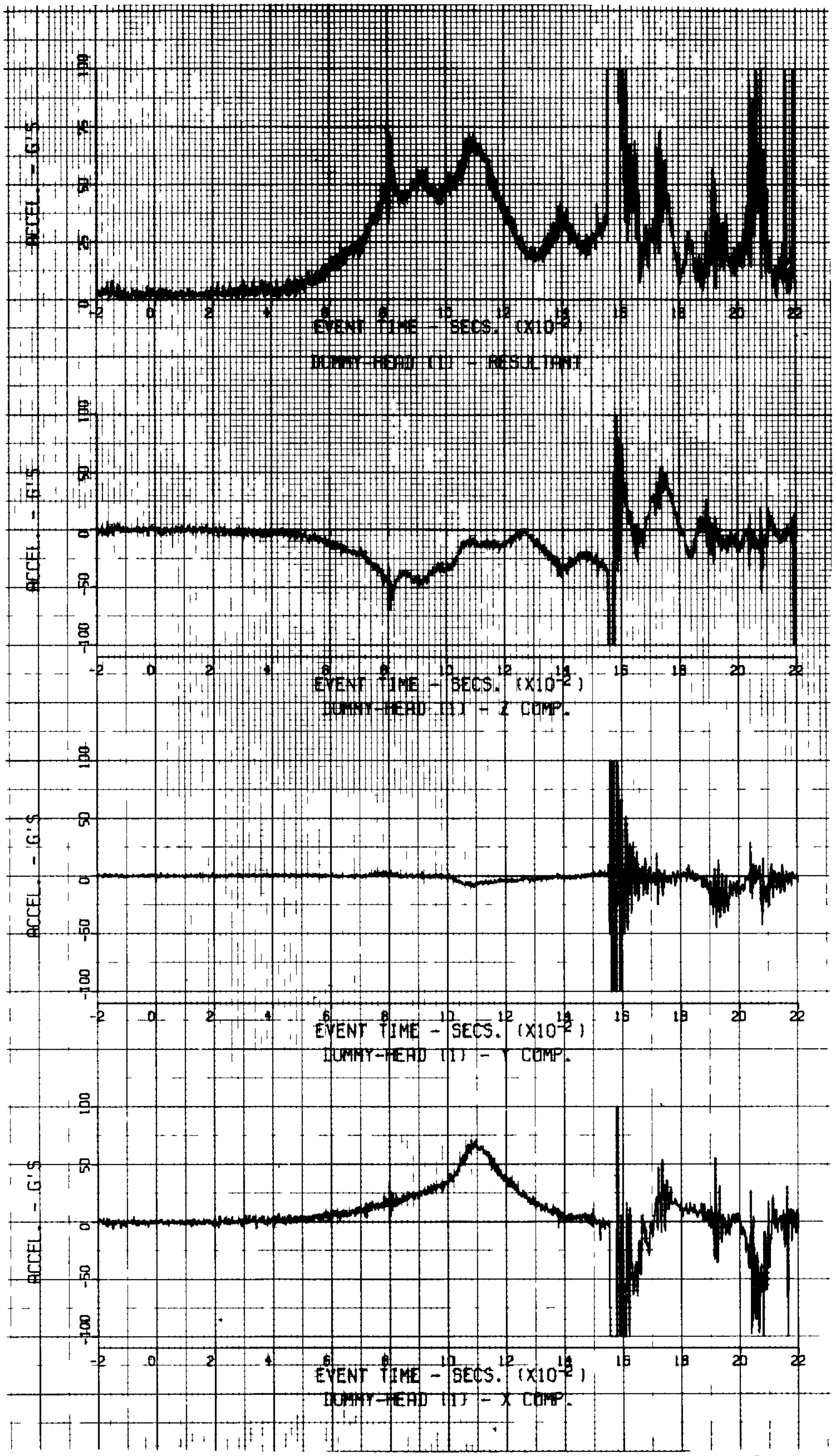


a. DUMMY CONFIGURATION FOR SLED TEST



b. DUMMY POSITION AFTER SLED TEST

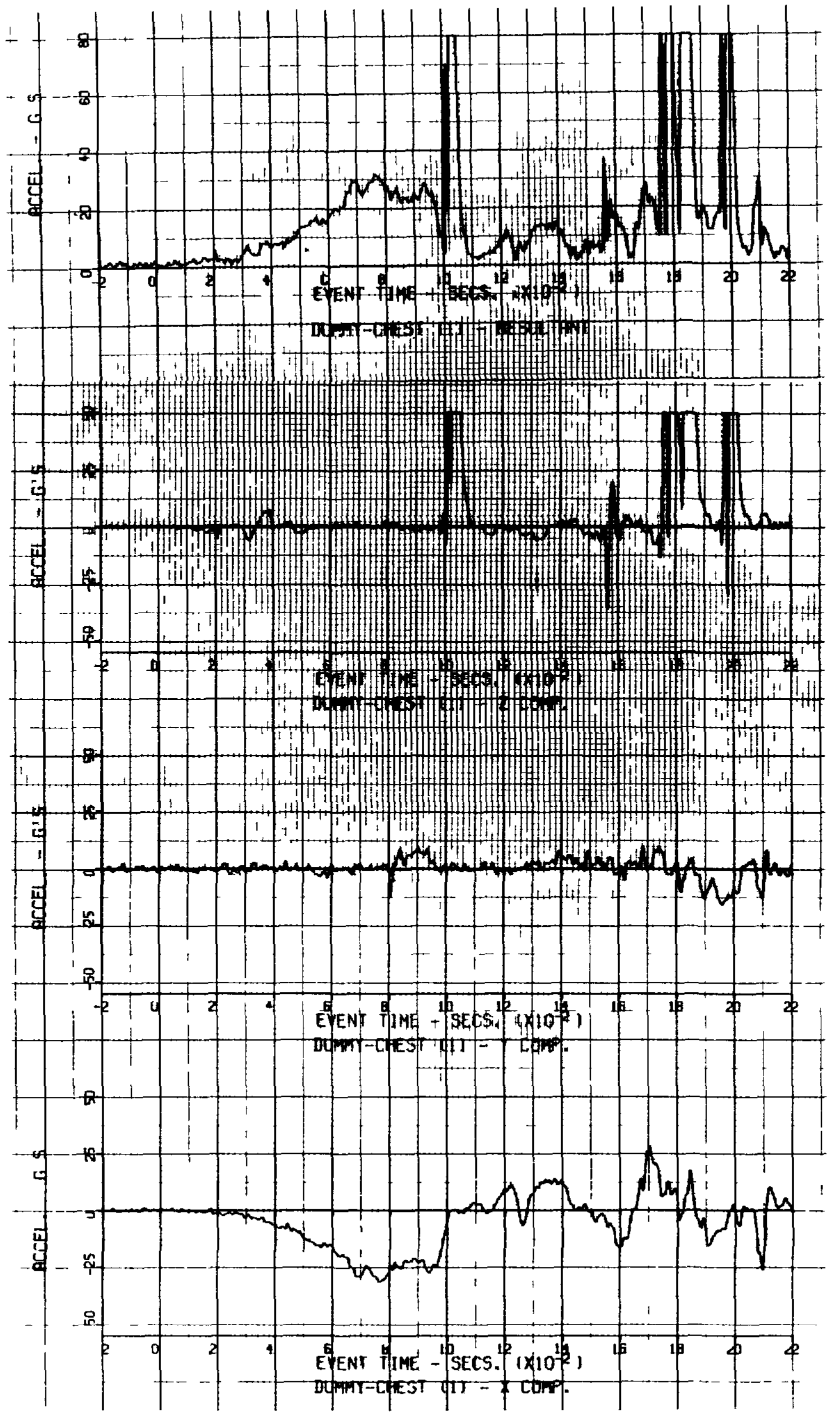
Figure 25 SLED TEST OF SIERRA 292-1295 DUMMY RESTRAINED BY LAP AND SHOULDER BELTS



842

(a) First of Three Repeats

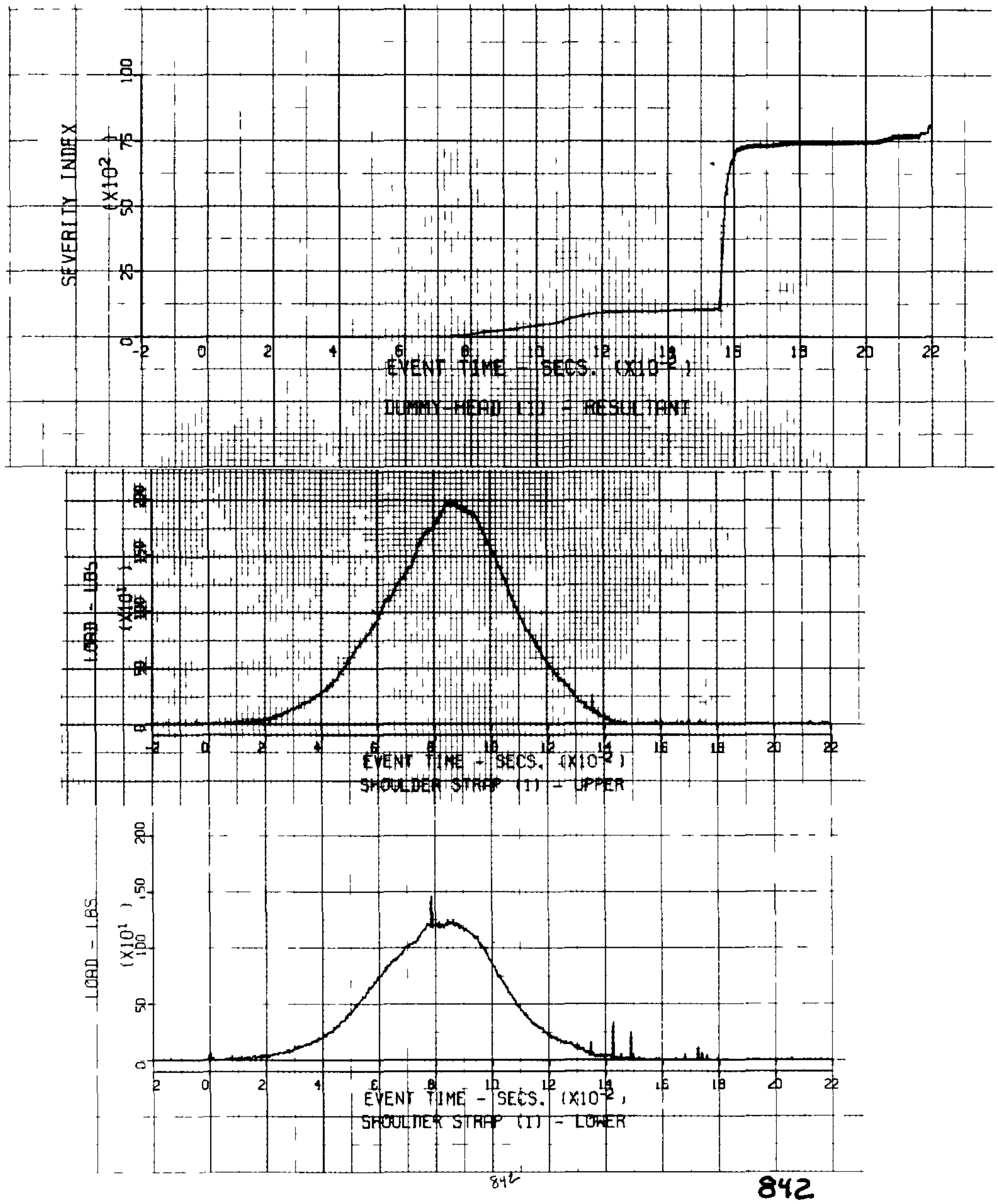
Figure 26 RESPONSE OF THE SIERRA MODEL 292-1295 DUMMY IN A FOUR POINT RESTRAINT SYSTEM. BELTS PRELOADED TO 5 LBS.



842

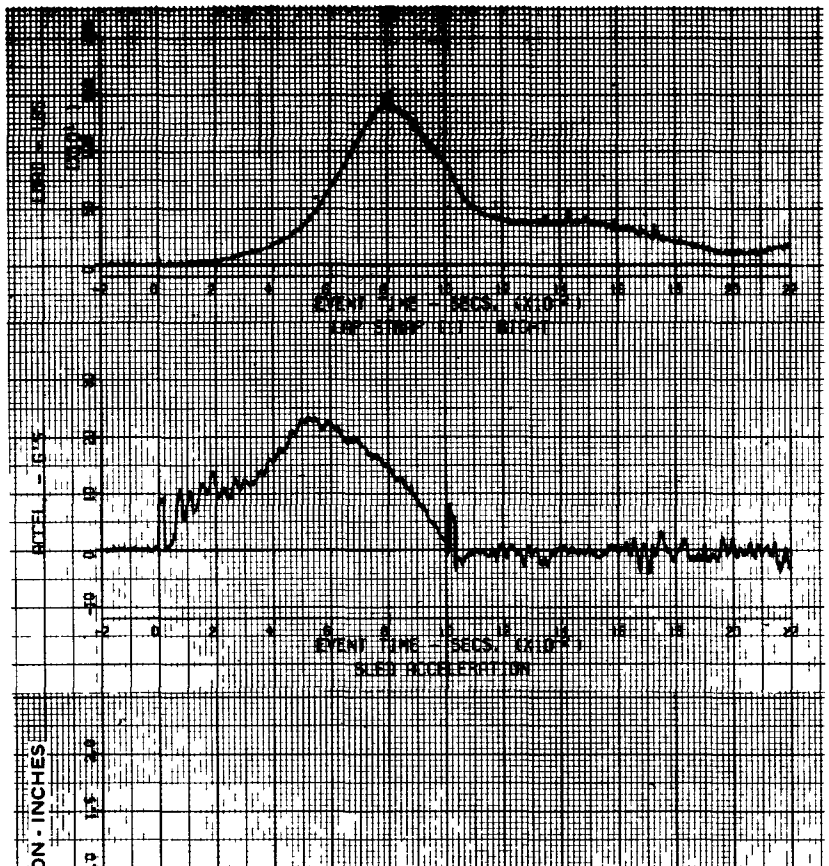
(a) Cont'd.

Figure 26 (Cont'd.)



(a) Cont'd.

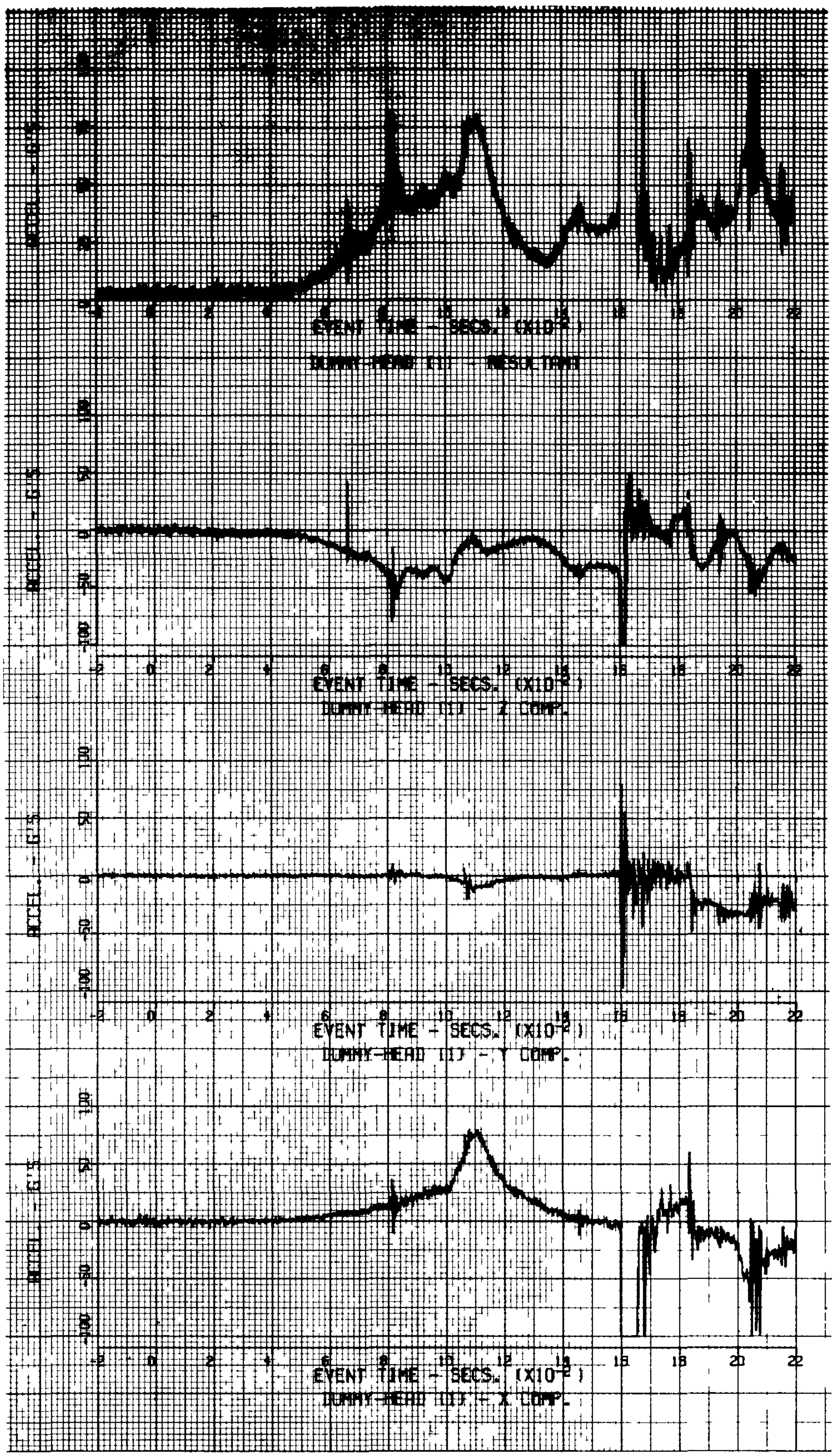
Figure 26 (Cont'd.)



842

(a) Cont'd.

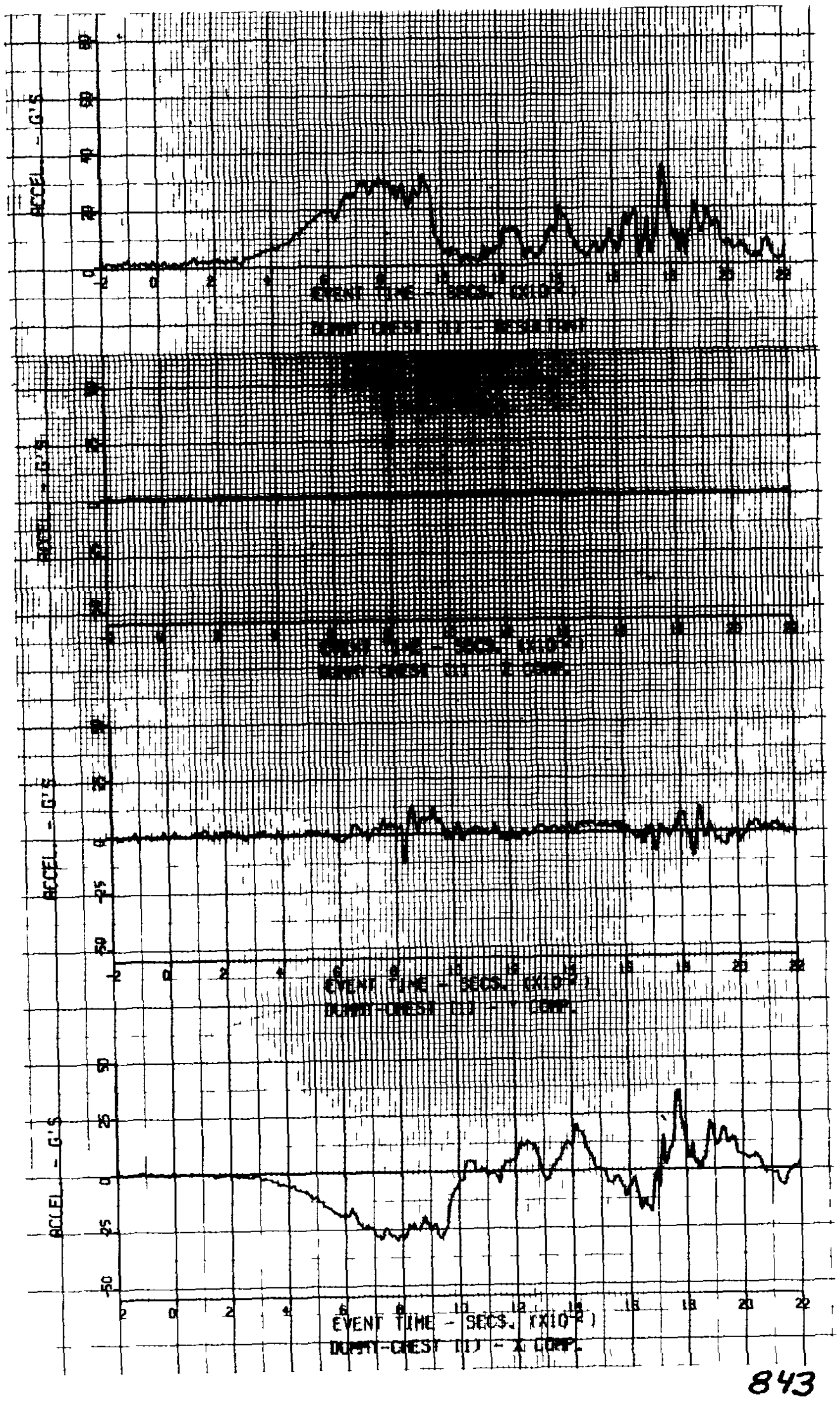
Figure 26 (Cont'd.)



843

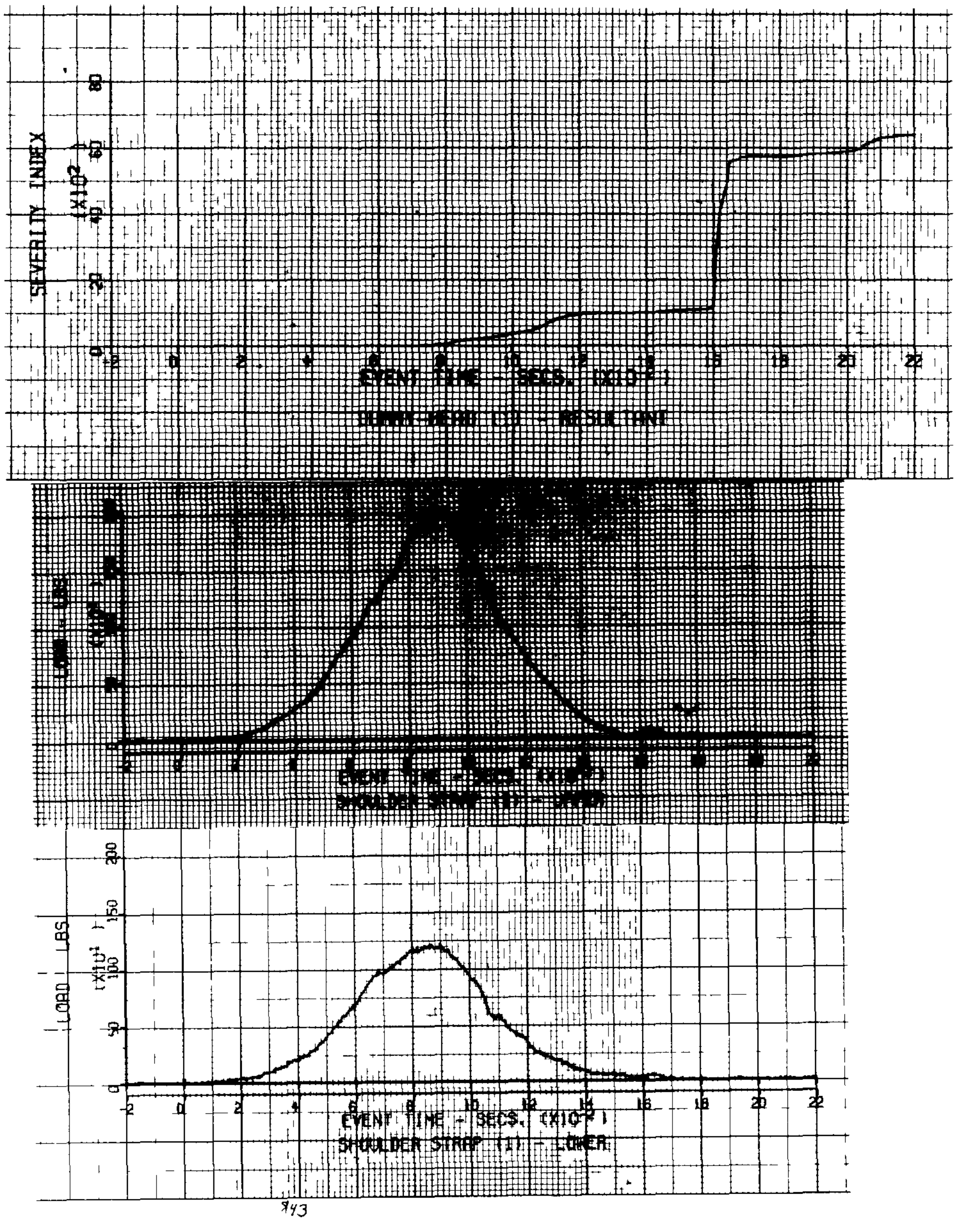
(b) Second of Three Repeats

Figure 26 (Cont'd.)



(b) Cont'd.

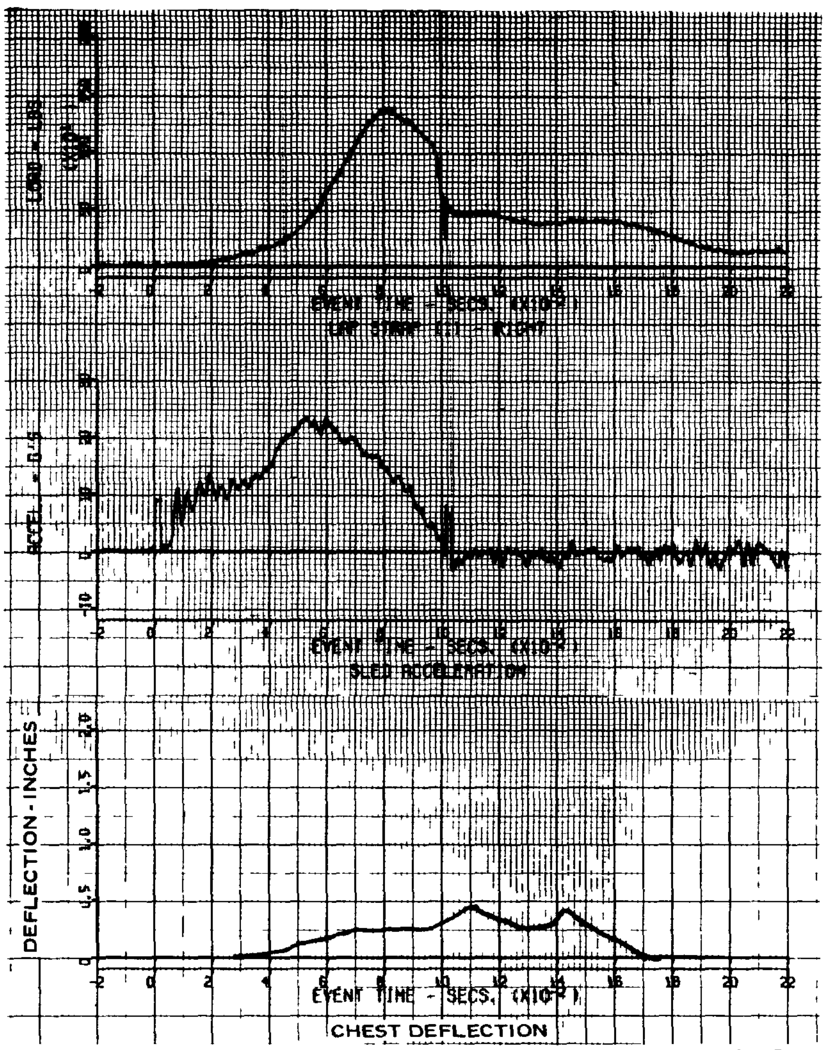
Figure 26 (Cont'd.)



843

(b) Cont'd.

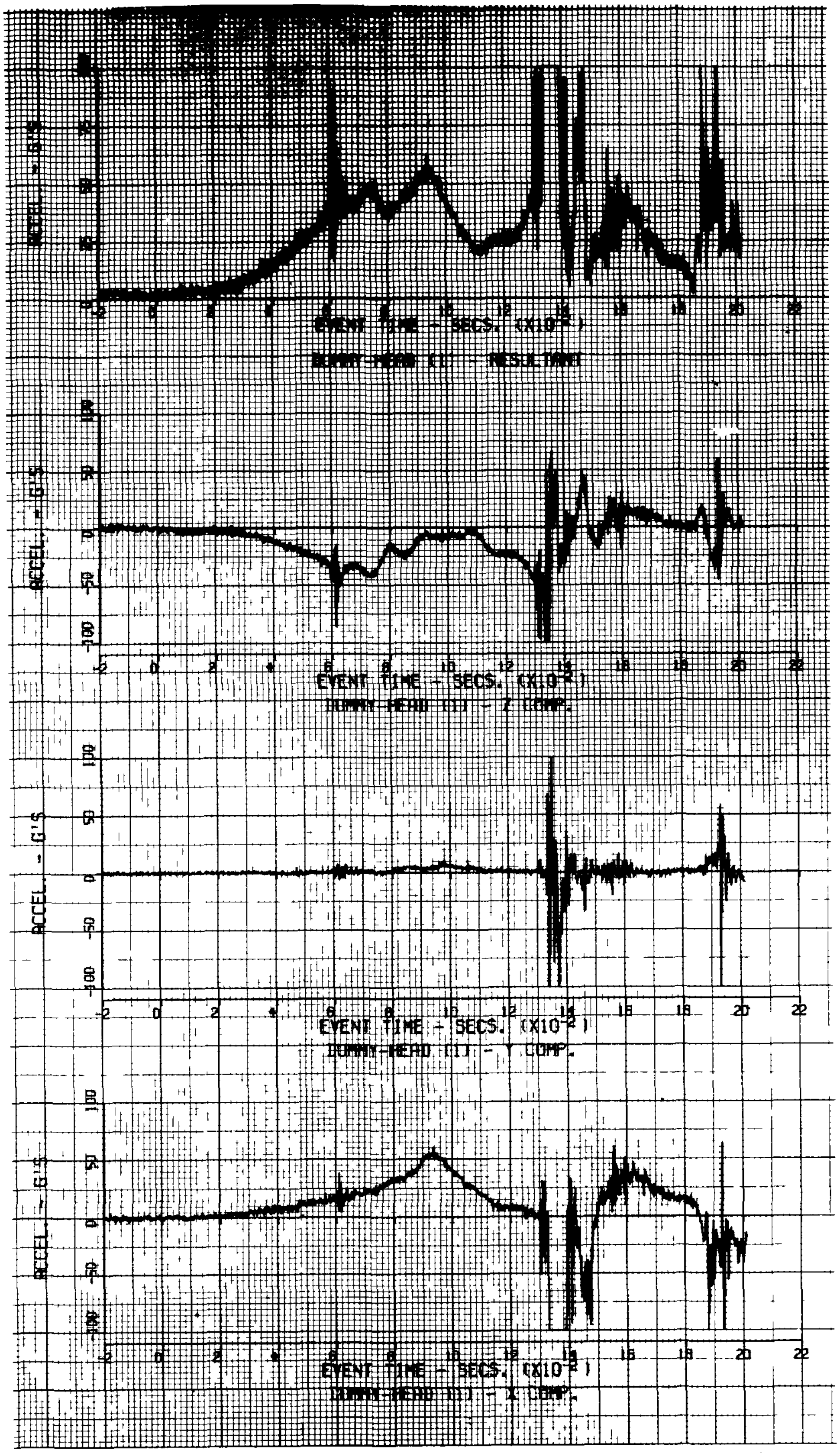
Figure 26 (Cont'd.)



843

(b) Cont'd,

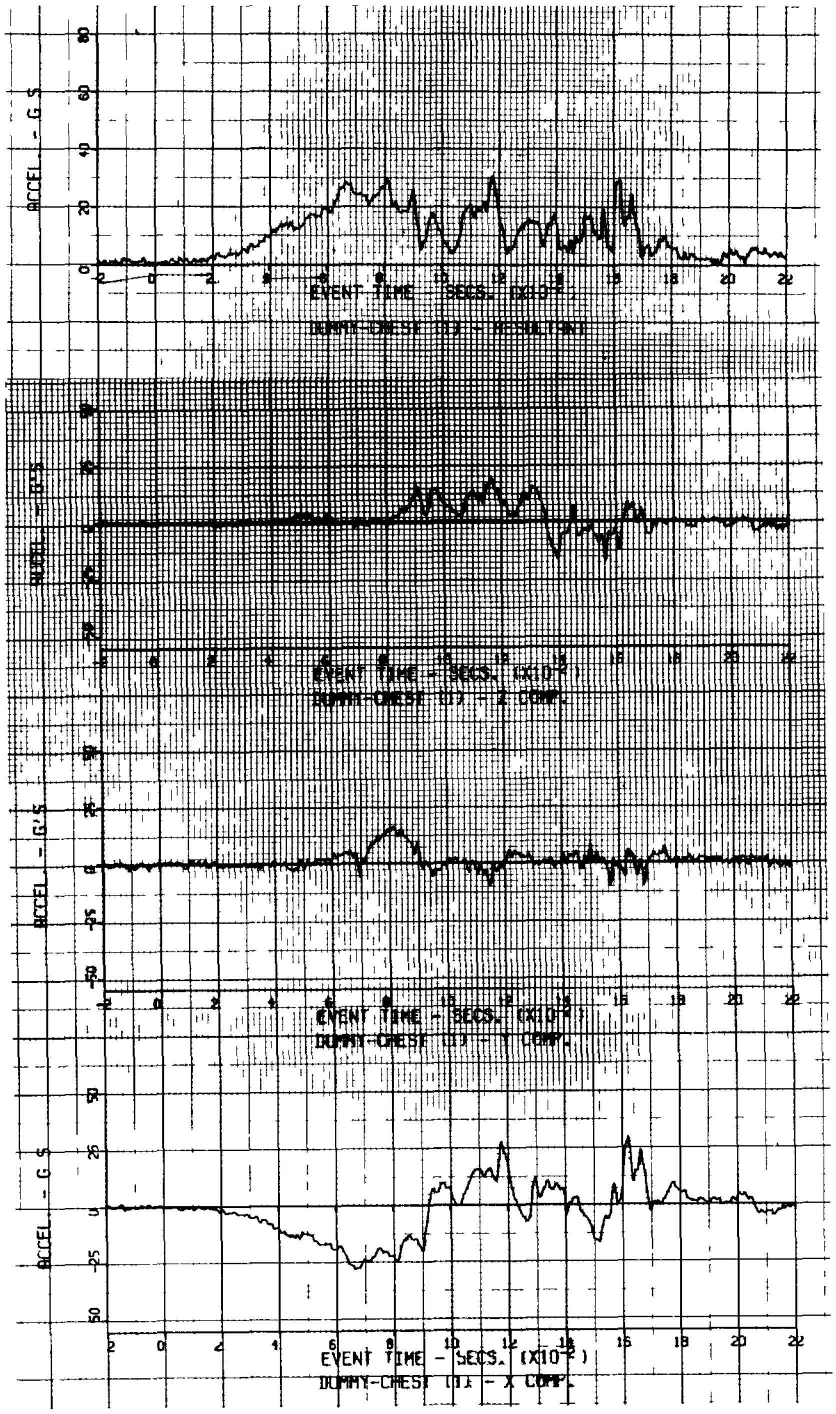
Figure 26 (Cont'd.)



844

(c) Third of Three Repeats

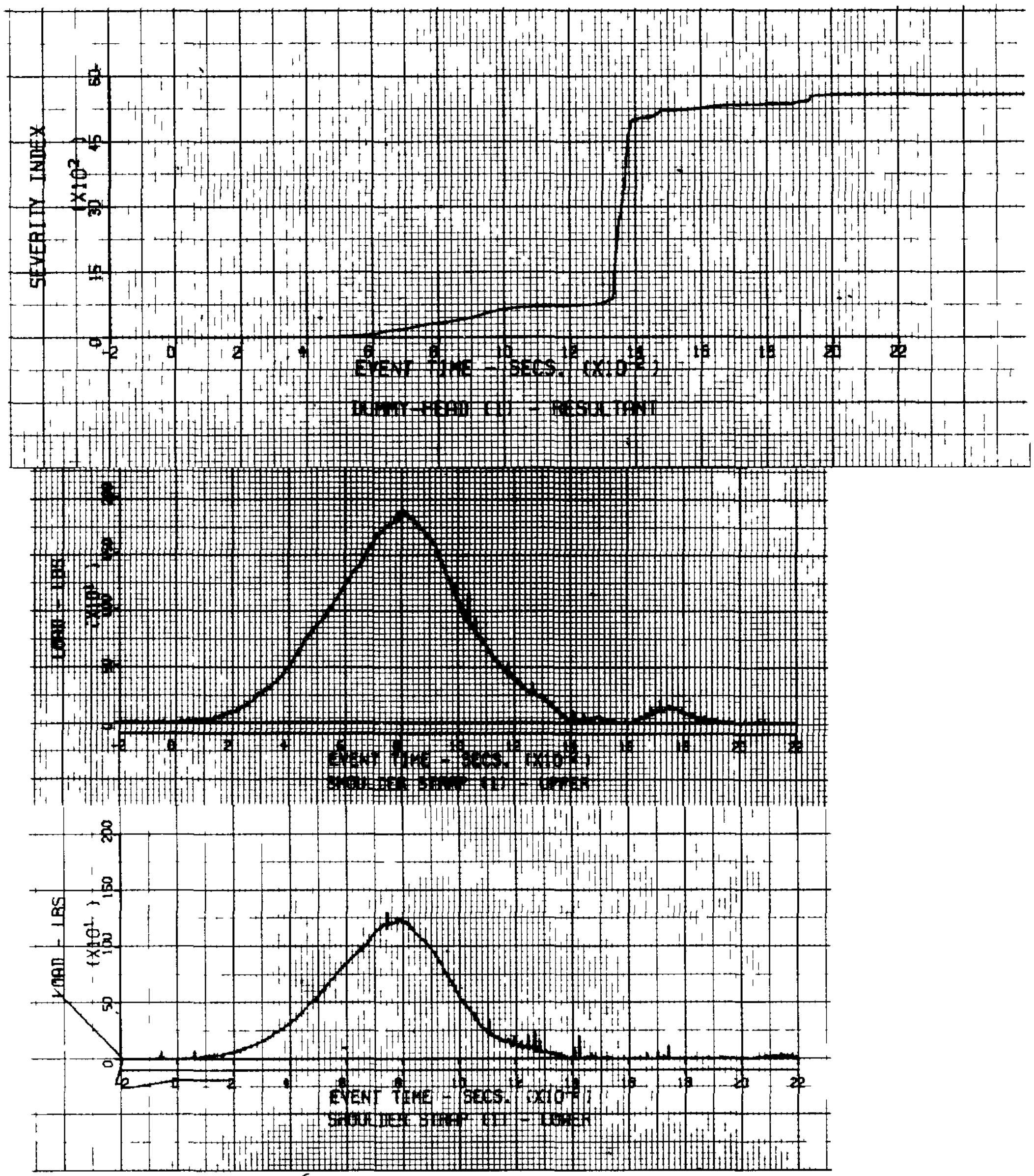
Figure 26 (Cont'd.)



844

(c) Cont'd.

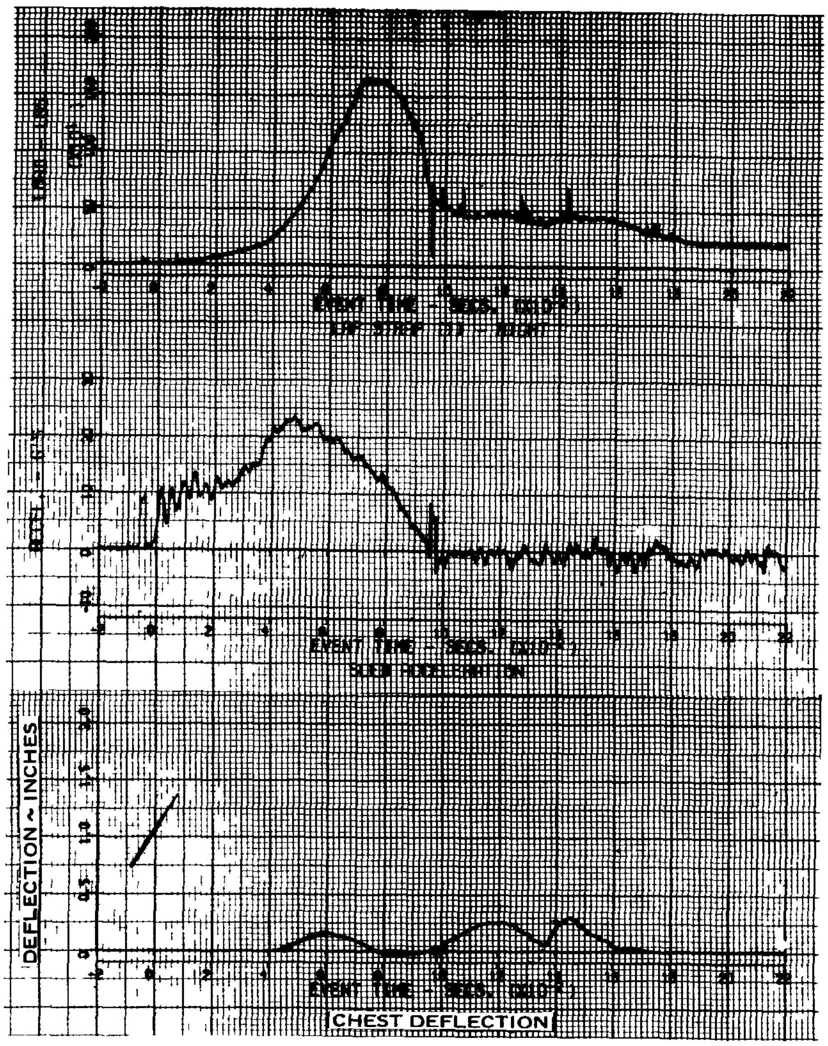
Figure 26 (Cont'd.)



844

(c) Cont'd.

Figure 26 (Cont'd.)



844

(c) Cont'd.

Figure 26 (Cont'd.)

TABLE 10

MEAN, STANDARD DEVIATION AND COEFFICIENT OF VARIATION OF HEAD INJURY CRITERIA AND HEAD SEVERITY INDEX FOR THE THREE SLED TESTS PERFORMED WITH THE SIERRA 292-1295 DUMMY

Run No.	HIC No.	Mean Value	Standard Deviation	Coefficient of Variation	Severity Index	Mean Value	Standard Deviation	Coefficient of Variation
842	858				1004			
843	828	786	100	.127	1020	935	187	.201
844	671				780			

The peak chest accelerations of approximately 32, 32, and 30 g's respectively for the three runs were very comparable to the mid-30g values obtained with the 50th percentile Sierra and Alderson dummies in the same restraint configuration. The chest deflection measurements recorded from the potentiometer in the chest cavity appear to be low compared to the deflection observed in the motion pictures, and it is possible that lateral movement of the anterior chest wall caused a low indicated deflection reading from the potentiometer. This potential problem is not unique to this dummy design, but is a problem inherent in the measurement method.

The gross body movements during the event (as shown by the motion pictures) were similar to those observed with the 50th percentile dummies, with the exceptions of the amount of forward movement allowed by the belts, and the severe submarining that occurred in all of the sled runs. The 95th percentile dummy forward travel of the torso against the restraint belts was 8 to 9 inches, as compared to 4 to 6 inches for the 50th percentile dummies. The forward travel of the 95th percentile dummy pelvic region continued after the upper torso forward motion had reached a maximum, pulling the torso down and under the lap belt by about 7 inches, such that this "submarining" motion is not stopped until the lower portion of the rib cage reaches the lap belt. The flat portion of the buttocks swings forward by about 18 inches and remains in that forward position (even through the deceleration phase of the sled run). This severe, non-returning submarining occurred in the three test runs and one preliminary run. For the 50th percentile sled tests under the same configuration, slight (1 to 2 inches under the lap belt) submarining occurred in one of the seven runs with the Sierra dummy and moderate (2-4 inches under the lap belt) submarining occurred in four of the seven runs with the Alderson dummy. All of the 50th percentile dummies returned to an essentially upright position in the seat, with the buttocks flat on the seat but with the lap belt slightly higher on the torso, unlike the 95th percentile tests wherein there was no return to the upright position and the lap belt was against the rib cage as shown in Figure 25.

The reason for this much greater submarining action is not known. It should be emphasized that many factors not well understood enter into the mechanics of submarining, and minor design changes in the pelvic area could account for this phenomenon. The most obvious design factor is the increased mass of the thighs and lower pelvic regions (broader buttocks). This would increase the mass moment-arm about the submarining pivot point at the lap belt, however, past experience (references 5 and 6) has shown that the obvious geometrical factors are not necessarily the most critical. What can be said is that every attempt was made to maintain the same belt geometry and loading, seat geometry, and dummy placement geometry as was used in tests of the 50th percentile dummies. The instrumentation films verify that the initial side view belt angles matched the previous tests very closely, and that the location of the lap belt relative to the centerline of the thigh also was essentially the same, even though the bulk of the abdomen and thigh was greater. The seat deflection time history was nearly the same as with the 50th percentile dummies, however this factor is known to have little effect on the submarining phenomenon. Two design factors, spinal spring stiffness and pelvic region padding material, particularly over the iliac crests, would have a significant role in the submarining response, and attempts to remedy the situation should examine these two factors very closely.

The degree of submarining response measured in this 95th percentile dummy is considered to be very unrealistic, and the use of this dummy for belted occupant simulation is not recommended until this problem is resolved. If human occupants submarined in this manner, and were subjected to this severe an upper abdominal lap belt load, they would undoubtedly suffer internal injuries. The accident injury reports for impact velocities in excess of this test velocity do not, however, reveal this type of internal injury, indicating that this submarining response does not usually occur. The number of reported cases of accidents with injuries to lap and shoulder belted occupants is not yet sufficient to assign percentages with any statistical significance, however, as the injury information accrues, this question can be resolved.

5. REFERENCES

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